NASA Conference Publication 3016

Technology for Future NASA Missions: Civil Space Technology Initiative (CSTI) and Pathfinder

Proceedings of a joint AIAA/NASA
conference held in
Washington, D.C.
September 12—13, 1988

NASA

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Technology for Future NASA Missions: Civil Space Technology Initiative (CSTI) and Pathfinder

NASA

National Aeronautics
and Space Administration

Scientific and Technical
Information Division

1988

PREFACE

The Technology for Future NASA Missions Conference was held during the period of September 12-13, 1988 at the Capital Hilton in Washington, DC. The conference provided industry and university executives programmatic and technical information on OAST space technology efforts. The conference was jointly sponsored by the American Institute of Aeronautics and Astronautics and the National Aeronautics and Space Administration. First day proceedings were devoted to programmatic discussions of CSTI, Pathfinder, and the Research and Technology Base program. Second day activities included the coverage of technical efforts on a more detailed basis.

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TECHNOLOGY FOR FUTURE NASA MISSIONS

MONDAY, 12 SEPTEMBER 1988

TUESDAY, 13 SEPTEMBER 1988

Office of
Aeronautics and
Space
Technology

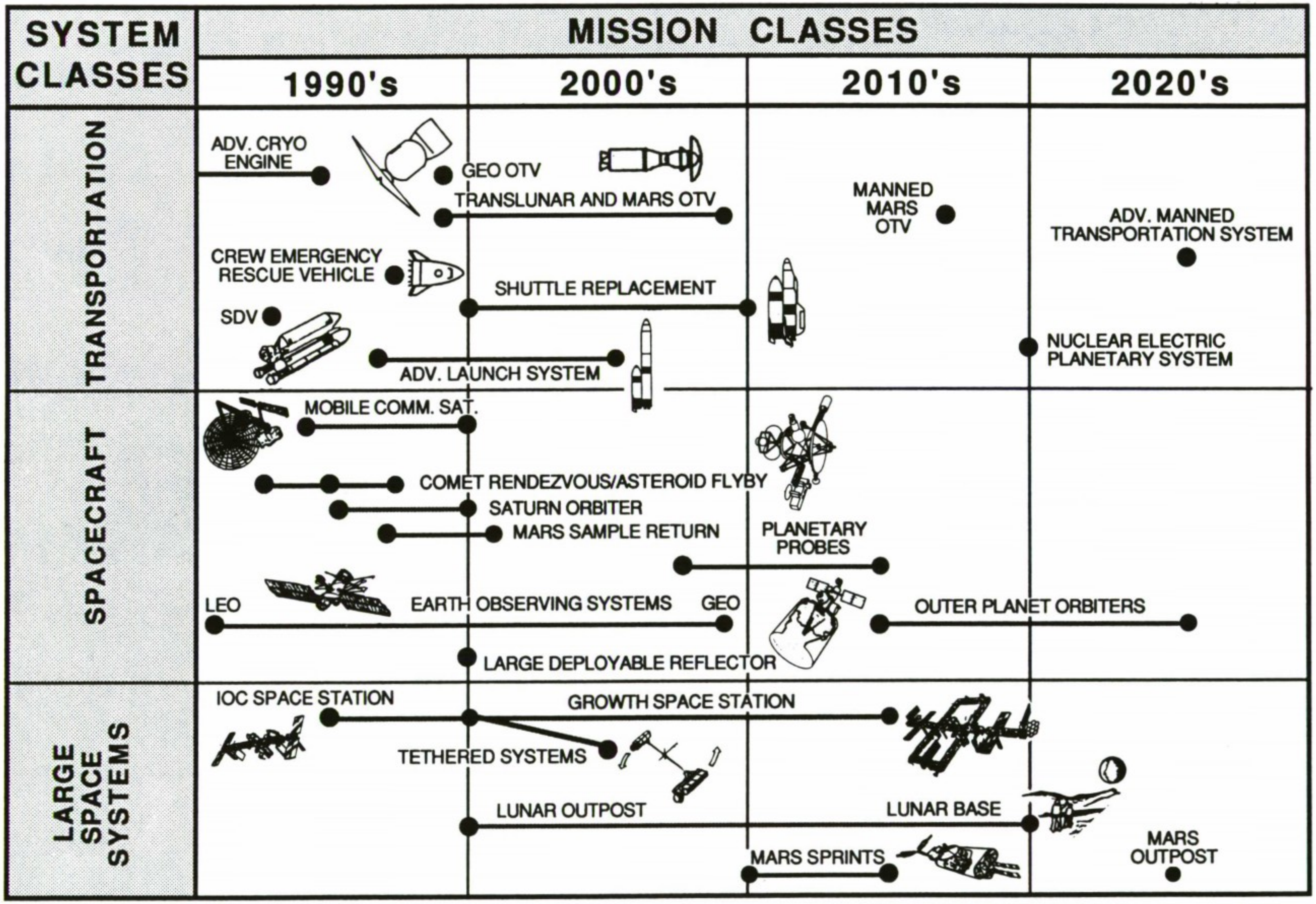
SPACE RESEARCH & TECHNOLOGY OVERVIEW

Presentation to

AIAA/OAST Conference on Space Technology

Frederick P. Povinelli
Director for Space
September 12, 1988

PROGRAM PLANNING FOCUS



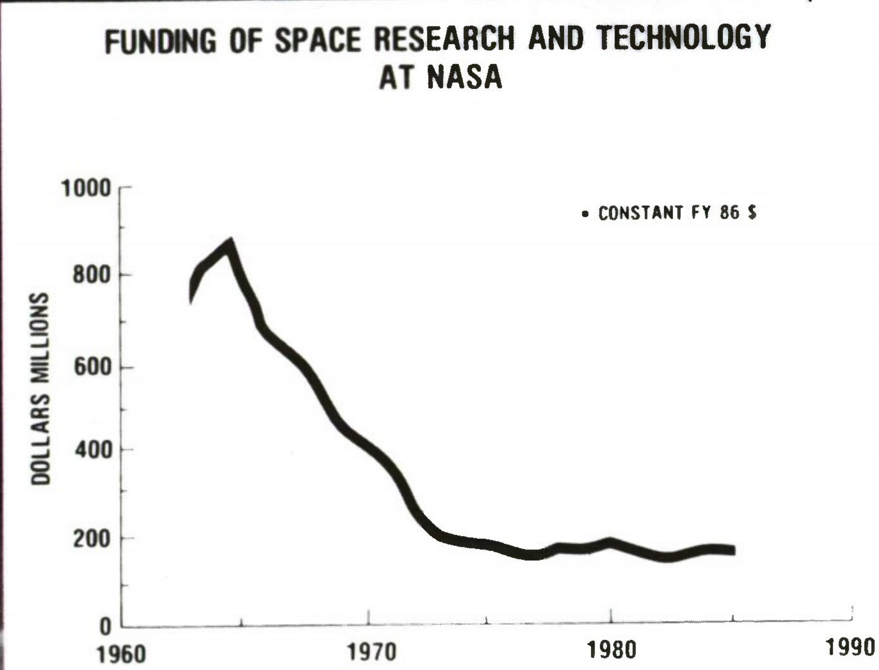
RS87-519(1)

EXTERNAL PROGRAM PLANNING INTERACTIONS

OAST

- NASA ADVISORY COUNCIL
- SPACE SYSTEMS AND TECHNOLOGY ADVISORY COMMITTEE
- AERONAUTICS AND SPACE ENGINEERING BOARD -- NRC
- SPACE TECHNOLOGY INTERAGENCY GROUP -- USAF
- WORKSHOPS/CONFERENCES
- IR&D COORDINATION
- INFORMAL TECHNOLOGY INTERCHANGES
- INDUSTRY AND UNIVERSITY SITE VISITS

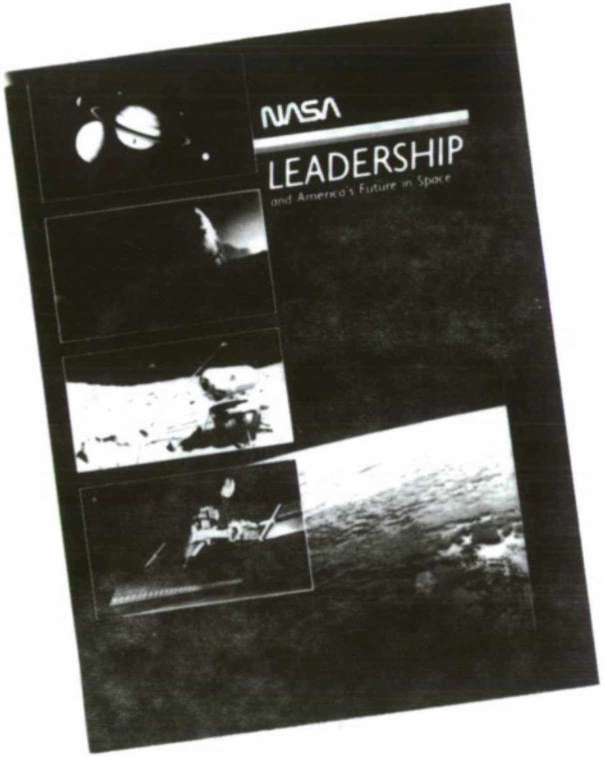
PIONEERING THE SPACE FRONTIER



We believe the Nation's space technology effort must be substantially increased. Because of its critical role in generating technological opportunities, NASA's space research and technology program should be tripled, moving from its current two percent of NASA's budget to six percent. This increase should be accompanied by a major challenge to NASA's technology advisory committees to develop and recommend a bold new technology thrust for 21st-century America.

NASA

OAST
RS86-723(3)



Until advanced technology programs like Project Pathfinder are initiated, the exciting goals of human exploration will always remain 10 to 20 years in the future.

SPACE R&T STRATEGY

OAST

REVITALIZE TECHNOLOGY FOR LOW EARTH ORBIT APPLICATIONS

DEVELOP TECHNOLOGY FOR EXPLORATION OF THE SOLAR SYSTEM

MAINTAIN FUNDAMENTAL R&T BASE

BROADEN PARTICIPATION OF UNIVERSITIES

EXTEND TECHNOLOGY DEVELOPMENT TO IN-SPACE EXPERIMENTATION

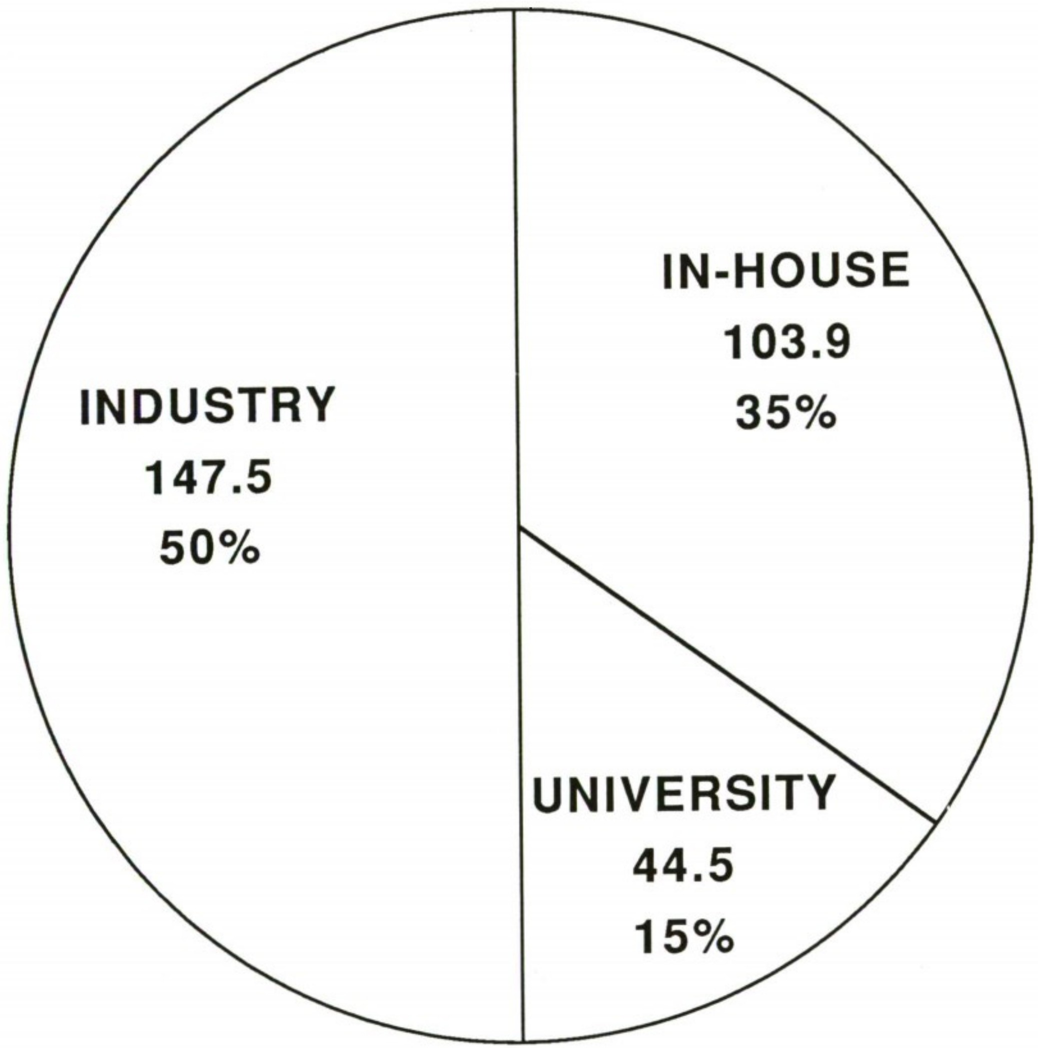
FACILITATE TECHNOLOGY TRANSFER TO USERS

SPACE R&D BUDGET

	FY 88	FY 89	PLANNED FY 90-94
R&T BASE	108.4	134.1	LEVEL-OF-EFFORT
CSTI	115.2	121.8	700
PATHFINDER	—	40.0	1000
TOTAL	223.6	295.9	

SPACE R&D 1989 BUDGET
($M)

OAST



TOTAL: $295.9M

88-2719

TOTAL SPACE R&T PROGRAM FUNDING 1989

($M)

OAST

R&D	295.9	R&T BASE CSTI PATHFINDER
R&PM	142.9	
C of F	6.1	
1989 SPACE TOTAL	444.9	

88-2720

TECHNOLOGY READINESS LEVELS AND PROGRAM PHASES

OAST

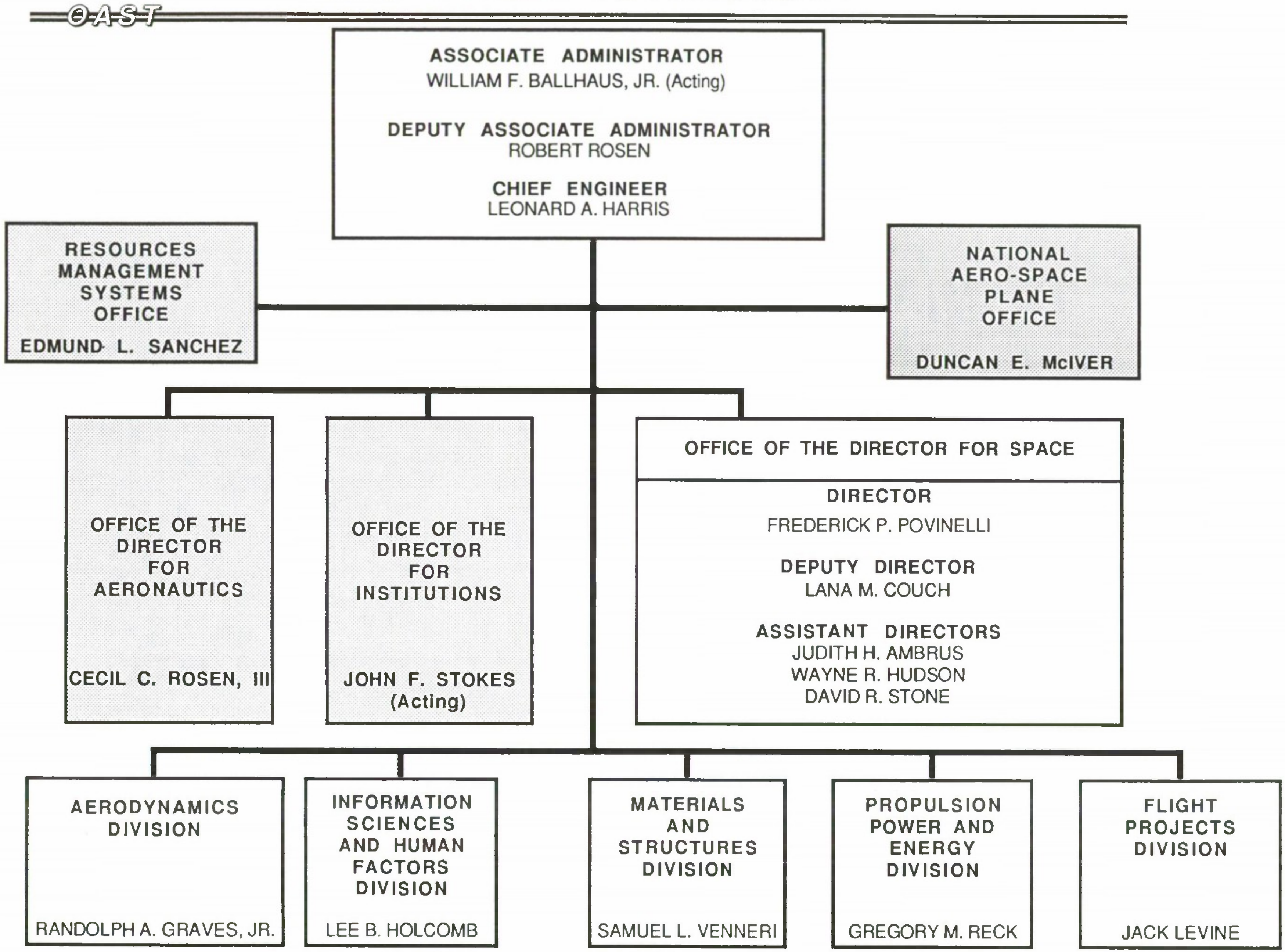
LEVEL 1	BASIC PRINCIPLES OBSERVED & REPORTED
LEVEL 2	TECHNOLOGY CONCEPT/APPLICATION FORMULATED
LEVEL 3	ANALYTICAL AND EXPERIMENTAL CRITICAL FUNCTION AND/OR CHARACTERISTIC PROOF-OF-CONCEPT
LEVEL 4	COMPONENT AND/OR BREADBOARD VALIDATION IN LABORATORY
LEVEL 5	COMPONENT AND/OR BREADBOARD DEMONSTRATION IN RELEVANT ENVIRONMENT
LEVEL 6	SYSTEM VALIDATION MODEL DEMONSTRATED IN SIMULATED ENVIRONMENT
LEVEL 7	SYSTEM VALIDATION MODEL DEMONSTRATED IN SPACE

R&T Base

Focused Program

JCM-0689

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY



AIAA/OAST SPACE TECHNOLOGY CONFERENCE

OAST

1ST DAY / 2ND DAY	CSTI	PATHFINDER	R&T BASE
PROPULSION POWER & LIFE SUPPORT	EARTH-TO-ORBIT BOOSTER HIGH CAPACITY POWER	PHYSICAL-CHEMICAL CLLS CHEMICAL TRANSFER PROP. CARGO VEHICLE PROPULSION CRYOGENIC FLUID DEPOT SURFACE POWER SPACE NUCLEAR POWER	PROPULSION SPACE ENERGY CONVERSION
INFORMATION SCIENCES & HUMAN FACTORS	SCIENCE SENSOR TECHNOLOGY DATA: HIGH RATE/CAPACITY AUTONOMOUS SYSTEMS ROBOTICS	PHOTONICS OPTICAL COMMUNICATIONS AUTONOMOUS LANDER AUTONOMOUS REND. & DOCKING PLANETARY ROVER EVA/SUIT HUMAN PERFORMANCE	INFORMATION SCIENCES SPACE DATA & COMMUNICATIONS CONTROLS & GUIDANCE HUMAN FACTORS
MATERIALS & STRUCTURES	PRECISION SEG. REFLECTORS CONTROL OF FLEXIBLE STRUCT.	RESOURCE PROCESSING PLANT SAMPLE ACQ., ANALYSIS, & PRE IN-SPACE ASSEMBLY & CONST.	MATERIALS AND STRUCTURES
FLIGHT PROJECTS	AEROASSIST FLIGHT EXP.		SPACE FLIGHT R&T
AEROTHERMO-DYNAMICS		HIGH ENERGY AEROBRAKING	AEROTHERMODYNAMICS

CONFERENCE PURPOSE

OAST

HAVE YOU CONCLUDE THAT:

- THE CIVIL SPACE PROGRAM HAS A BRIGHT FUTURE
- TECHNOLOGY ADVANCES ARE CRITICAL TO THAT FUTURE
- NASA IS COMMITTED TO A STRONGER TECHNOLOGY PROGRAM
- MORE EXTERNAL INVOLVEMENT IS REQUIRED
- IT'S TIME TO MAKE CONTACT WITH NASA MANAGERS
- IT'S APPROPRIATE TO REVIEW YOUR IR&D PLANS

NASA

OAST

CIVIL SPACE TECHNOLOGY INITIATIVE

DR. JUDITH H. AMBRUS
ASSISTANT DIRECTOR FOR SPACE
LARGE SPACE SYSTEMS

SPACE R&T STRATEGY

OAST

REVITALIZE TECHNOLOGY FOR LOW EARTH ORBIT APPLICATIONS

DEVELOP TECHNOLOGY FOR EXPLORATION OF THE SOLAR SYSTEM

MAINTAIN FUNDAMENTAL R&T BASE

BROADEN PARTICIPATION OF UNIVERSITIES

EXTEND TECHNOLOGY DEVELOPMENT TO IN-SPACE EXPERIMENTATION

FACILITATE TECHNOLOGY TRANSFER TO USERS

MISSION NEEDS

- TRANSPORTATION TO LOW EARTH ORBIT
  - PROPULSION
  - AEROBRAKING
- OPERATIONS IN LOW EARTH ORBIT
  - AUTONOMOUS SYSTEMS
  - TELEROBOTICS
  - POWER
- SCIENCE
  - STRUCTURES
  - SENSORS
  - DATA SYSTEMS

CSTI 88-020

BACKGROUND

- THE FIRST STEP IN REVITALIZING THE NATION'S CIVIL SPACE TECHNOLOGY BASE
- WILL FILL GAPS IN MANY TECHNOLOGY AREAS
- FOCUSED TECHNOLOGY EFFORT, WILL RESULT IN DEMONSTRATED / VALIDATED TECHNOLOGIES

EARTH TO ORBIT PROPULSION

OBJECTIVE:

PROVIDE A VALIDATED TECHNOLOGY BASE FOR THE DESIGN OF HIGH PERFORMANCE, LONG LIFE LOX/H2 AND LOX /HC ENGINES

- ENABLE FULLY REUSABLE VEHICLES TO REDUCE TRANSPORTATION COSTS

APPROACH:

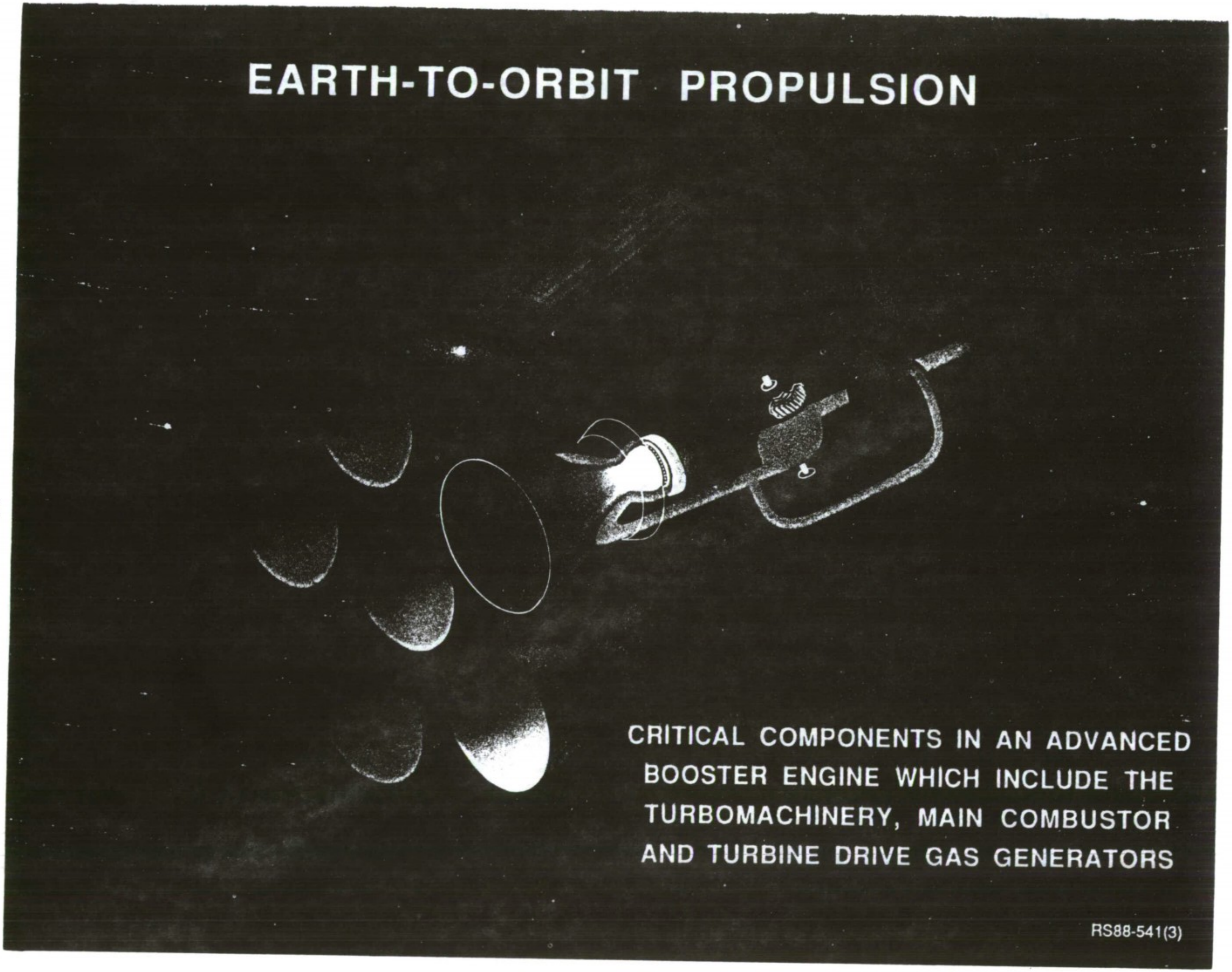
EXTEND KNOWLEDGE AND UNDERSTANDING OF ROCKET ENGINE CHEMICAL AND PHYSICAL PROCESSES BY BUILDING AND VALIDATING COMPONENTS AND HEALTH MONITORING DEVICES

EARTH TO ORBIT PROPULSION

MANAGEMENT

- LEAD OAST DIVISION
  - PROPULSION, POWER AND ENERGY DIVISION
- LEAD NASA FIELD CENTER
  - MARSHALL SPACE FLIGHT CENTER
- PARTICIPATING CENTER
  - LEWIS RESEARCH CENTER
- FY 1989 BUDGET : $ 29.1 M

CSTI 88-019


EARTH-TO-ORBIT PROPULSION
CRITICAL COMPONENTS IN AN ADVANCED BOOSTER ENGINE WHICH INCLUDE THE TURBOMACHINERY, MAIN COMBUSTOR AND TURBINE DRIVE GAS GENERATORS
RS88-541(3)

BOOSTER TECHNOLOGY

OAST CSTI

OBJECTIVE:

DEVELOP THE ENGINE TECHNOLOGY FOR ALTERNATE PROPULSION CONCEPTS FOR THE SPACE SHUTTLE SOLID ROCKET BOOSTER (SRB)

- PROVIDE A SAFE ABORT OPTION
- PROVIDE THE ABILITY TO TAILOR THRUST
- PROVIDE THE POTENTIAL FOR ADDITIONAL IMPULSE

APPROACH:

EXPLORE ALTERNATIVE BOOSTER TECHNOLOGIES INCLUDING LIQUID AND HYBRID CONCEPTS

BOOSTER TECHNOLOGY

OAST CSTI

MANAGEMENT

- LEAD OAST DIVISION

  PROPULSION, POWER, AND ENERGY DIVISION

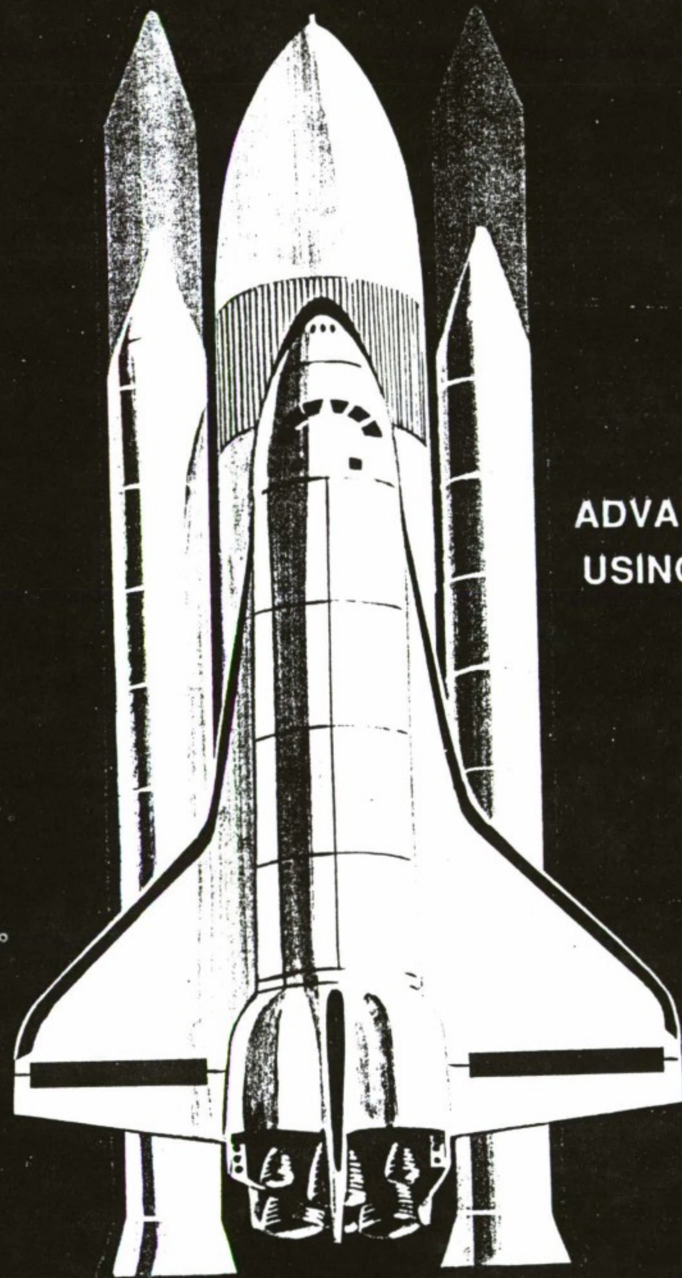
- LEAD NASA FIELD CENTER

  MARSHALL SPACE FLIGHT CENTER

- FY 1989 BUDGET: $ 9.0 M

CSTI 88-019

BOOSTER TECHNOLOGY



ADVANCED HYBRID BOOSTERS
USING ADVANCED MATERIALS

RS88-542(3)

AEROASSIST FLIGHT EXPERIMENT

OAST CSTI

OBJECTIVE:

INVESTIGATE THE CRITICAL VEHICLE TECHNOLOGIES AND UPPER ATMOSPHERIC CHARACTERISTICS APPLICABLE TO THE DESIGN OF AN AEROASSISTED ORBITAL TRANSFER VEHICLE

- PROVIDE A LARGE SAVING IN PROPELLANT WHICH COULD DOUBLE THE PAYLOAD WEIGHT

APPROACH:

CONDUCT A REENTRY FLIGHT EXPERIMENT THROUGH THE UPPER ATMOSPHERE TO VALIDATE DESIGN CODES

AEROASSIST FLIGHT EXPERIMENT

MANAGEMENT

- LEAD OAST DIVISION

  FLIGHT PROJECTS DIVISION

- LEAD NASA FIELD CENTER

  MARSHALL SPACE FLIGHT CENTER

- PARTICIPATING CENTERS

  LANGLEY RESEARCH CENTER
  JOHNSON SPACE FLIGHT CENTER
  AMES RESEARCH CENTER

- FY 1989 BUDGET: $ 13.3 M

CSTI 88-019


AEROASSIST FLIGHT EXPERIMENT
AEROASSIST FLIGHT
SPACECRAFT DECELARATING IN
EARTH'S ATMOSPHERE

ROBOTICS

OAST CSTI

OBJECTIVE:

DEVELOP THE TECHNOLOGY BASE REQUIRED TO EVOLVE FROM TELEOPERATIONS TO TELEROBOTICS

- PERFORM SPACE ASSEMBLY AND CONSTRUCTION, SATELLITE SERVICING, AND PLATFORM MAINTENANCE AND REPAIR EFFICIENTLY AND SAFELY

APPROACH:

DEVELOP COMPONENTS TO BE EVALUATED IN AN INTEGRATED TESTBED THAT WILL DEMONSTRATE CAPABILITIES SUCH AS STOPPING SLOWLY SPINNING SPACECRAFT, PERFORMING SIMPLE SERVICING, ETC.

ROBOTICS

OAST CSTI

MANAGEMENT

- LEAD OAST DIVISION

  INFORMATION SCIENCES AND HUMAN FACTORS DIVISION

- LEAD NASA FIELD CENTER

  JET PROPULSION LABORATORY

- PARTICIPATING CENTERS

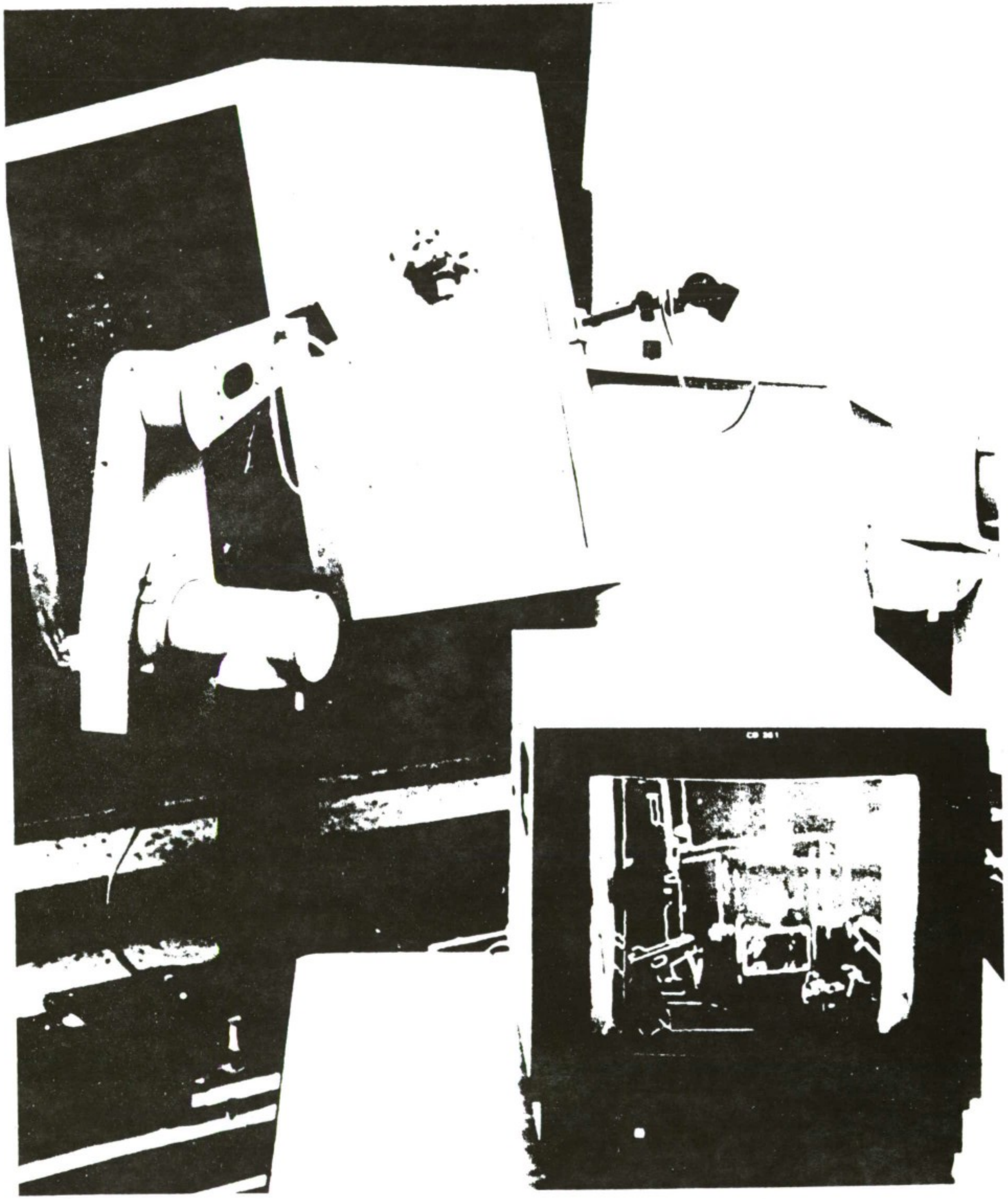
  GODDARD SPACE FLIGHT CENTER
  LANGLEY RESEARCH CENTER
  JOHNSON SPACE CENTER

- FY 1989 BUDGET : $ 13.8 M

CSTI 88-019

ROBOTICS

ADVANCED DUAL ARM MANIPULATOR WITH DEMONSTRATED VISUAL TRACKING CAPABILITY



RS88-557(3)

SCIENCE SENSOR TECHNOLOGY

OBJECTIVE:

DEVELOP AN ADVANCED SENSOR TECHNOLOGY BASE FOR SCIENTIFIC SENSING INVESTIGATION OF EARTH SYSTEMS, THE SOLAR SYSTEM, AND THE UNIVERSE

- DEVELOP PASSIVE, SENSITIVE, RELIABLE, AND IMPROVED IMAGING CAPABILITY OF SPACE-BASED ADVANCED DETECTORS
- KEEP COSTS TO A MINIMUM

APPROACH:

DEVELOP ADVANCED TUNABLE SOLID STATE AND GAS LASERS AND ACCOMPANYING ADVANCED TECHNOLOGY

SCIENCE SENSOR TECHNOLOGY

MANAGEMENT

- **LEAD OAST DIVISION**

  INFORMATION SCIENCES AND HUMAN FACTORS DIVISION

- **LEAD NASA CENTER**

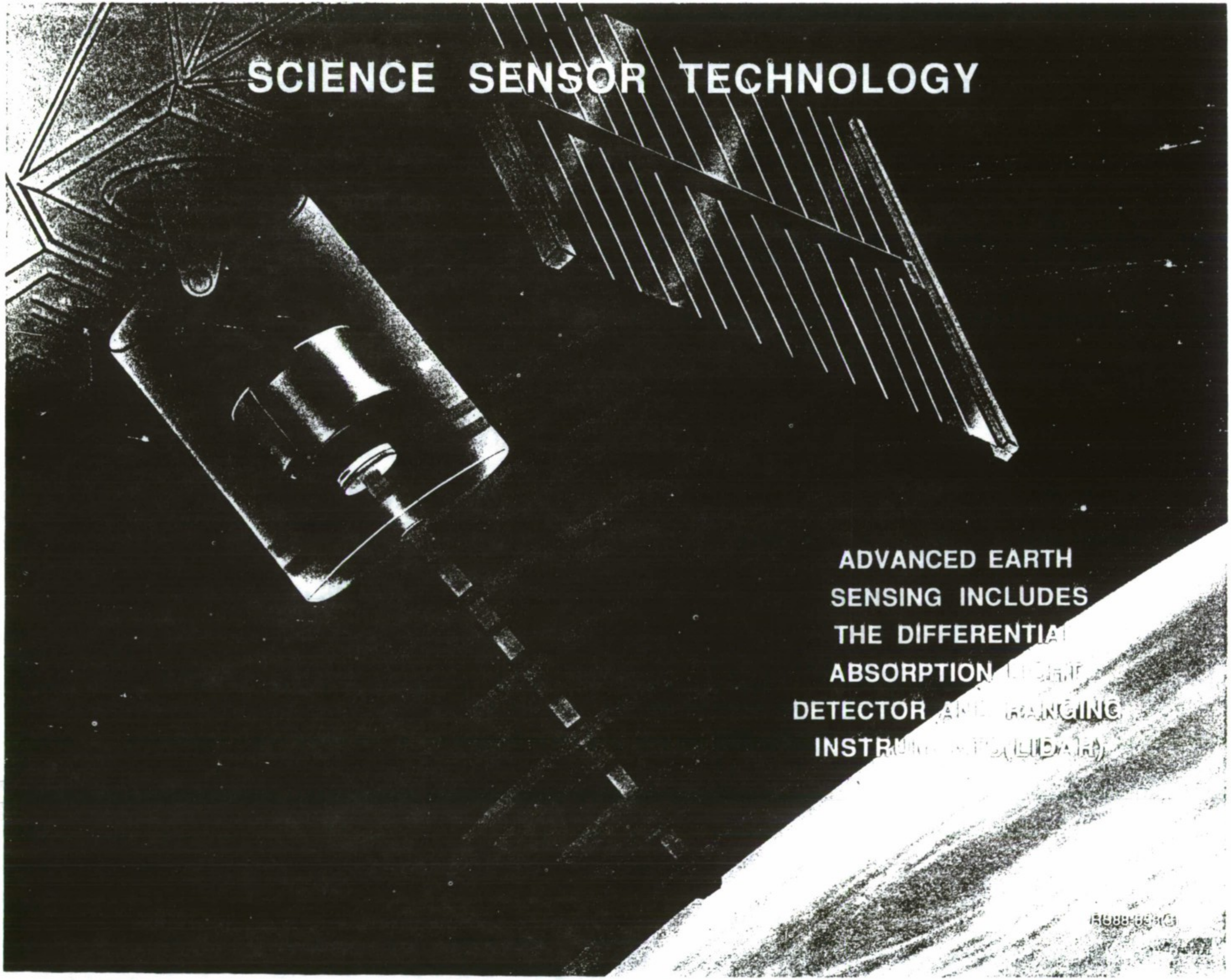
  LANGLEY RESEARCH CENTER

- **PARTICIPATING CENTERS**

  GODDARD SPACE FLIGHT CENTER
  JET PROPULSION LABORATORY
  MARSHALL SPACE FLIGHT CENTER
  AMES RESEARCH CENTER
  LEWIS RESEARCH CENTER

- **FY 1989 BUDGET : $ 7.8M**

CSTI 88-019


SCIENCE SENSOR TECHNOLOGY
ADVANCED EARTH
SENSING INCLUDES
THE DIFFERENTIA
ABSORPTION
DETECTOR
INSTR

AUTONOMOUS SYSTEMS

OBJECTIVE:

DEVELOP AN ARTIFICIAL INTELLIGENCE TECHNOLOGY BASE FOR EFFICIENT AUTONOMOUS OPERATIONS IN SPACE AND ON THE GROUND

- FREE HUMAN RESOURCES FROM ROUTINE OPERATIONS
- DECREASE COSTS OF SPACE OPERATIONS

APPROACH:

DEMONSTRATE KNOWLEDGE BASED DECISION MAKING, MACHINE LEARNING, UNCERTAINTY PLANNING AND SIMILAR ADVANCED CONCEPTS

AUTONOMOUS SYSTEMS

OAST CSTI

MANAGEMENT

- LEAD OAST DIVISION
  INFORMATION SCIENCES AND HUMAN FACTORS DIVISION
- LEAD NASA FIELD CENTER
  AMES RESEARCH CENTER
- PARTICIPATING CENTER
  JOHNSON SPACE CENTER
- FY 1989 BUGET: $ 12.1 M

CSTI 88-019

AUTONOMOUS SYSTEMS

AUTONOMOUS SYSTEMS APPLICATIONS
AIDING THE INTEGRATED COMMUNICATIONS
OFFICER (INCO) IN MISSION CONTROL CENTER

RS88-559(3)

DATA: HIGH RATE/CAPACITY

OAST | CSTI

<u>OBJECTIVE:</u>

DEVELOP HIGH SPEED, HIGH VOLUME DATA HANDLING TECHNOLOGIES AND SYSTEMS NEEDED TO MEET THE SCIENTIFIC AND OPERATIONAL REQUIREMENTS OF FUTURE MISSIONS

- PERFORM RECOGNITION, EXTRACTION, AND TRANSMISSION OF SIGNIFICANT OBSERVATIONS ON-BOARD THE SPACECRAFT
- ENSURE HIGH SCIENTIFIC RETURNS WHILE KEEPING OPERATIONAL COSTS LOW

<u>APPROACH:</u>

PRODUCE, TEST AND VALIDATE FLIGHT QUALIFIABLE COMPONENTS FOR ON-BOARD DATA PROCESING AND STORAGE

DATA : HIGH RATE /CAPACITY

MANAGEMENT

- LEAD OAST DIVISION

  INFORMATION SCIENCES AND HUMAN FACTORS DIVISION

- LEAD NASA FIELD CENTER

  LANGLEY RESEARCH CENTER

- PARTICIPATING CENTERS

  GODDARD SPACE FLIGHT CENTER
  JET PROPULSION LABORATORY

- FY 1989 BUDGET : $ 8.1 M

CSTI 88-019

DATA: HIGH RATE/CAPACITY

CONTROL OF FLEXIBLE STRUCTURES

OBJECTIVE:

DEVELOP STRUCTURES AND CONTROLS TECHNOLOGY THAT WILL ENABLE THE DESIGN VERIFICATION AND QUALIFICATION OF PRECISION SPACE STRUCTURES AND LARGE FLEXIBLE SPACE SYSTEMS

- INCREASE SURFACE AND POINTING PRECISION AND USE OF ARTICULATED MOVING COMPONENTS

APPROACH:

VERIFY THE ANALYSIS AND DESIGN METHODS THROUGH GROUND TESTS AND IN-SPACE FLIGHT EXPERIMENTS

CONTROL OF FLEXIBLE STRUCTURES

OAST — CSTI

MANAGEMENT

- LEAD OAST DIVISION

  MATERIALS AND STRUCTURES DIVISION

- LEAD NASA FIELD CENTER

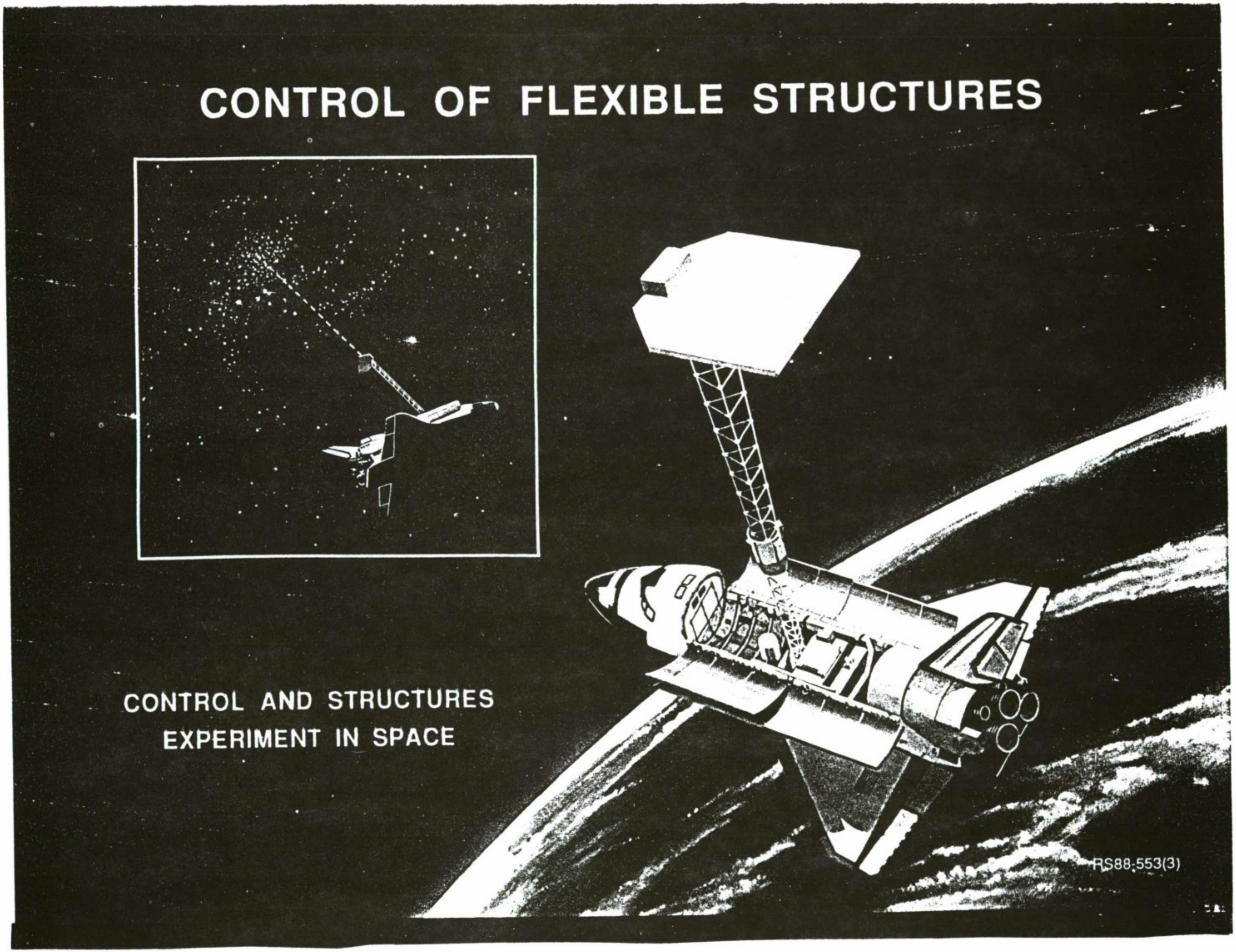
  LANGLEY RESEARCH CENTER

- PARTICIPATING CENTERS

  MARSHALL SPACE FLIGHT CENTER
  JET PROPULSION LABORATORY
  GODDARD SPACE FLIGHT CENTER

- FY 1989 BUDGET: $15.7 M

CSTI 88-019


CONTROL OF FLEXIBLE STRUCTURES
CONTROL AND STRUCTURES
EXPERIMENT IN SPACE
RS88-553(3)

PRECISION SEGMENTED REFLECTORS

OBJECTIVE:

DEVELOP THE MATERIALS, STRUCTURES, AND CONTROL TECHNOLOGY TO ENABLE THE DESIGN OF LARGE, LIGHT-WEIGHT, HIGH PRECISION ORBITING ASTRONOMICAL INSTRUMENTS

- DEVELOP LIGHT-WEIGHT AND SPACE ERECTABLE/DEPLOYABLE SYSTEMS FOR MAKING DEEP SPACE OBSERVATIONS IN THE SUB-MILLIMETER AND SMALLER PORTION OF THE SPECTRUM

APPROACH:

FABRICATE HIGH SURFACE PRECISION PANELS AND CONDUCT SYSTEM LEVEL VALIDATION TESTING

PRECISION SEGMENTED REFLECTORS

MANAGEMENT

- LEAD OAST DIVISION
  - MATERIALS AND STRUCTURES DIVISION
- LEAD NASA FIELD CENTER
  - JET PROPULSION LABORATORY
- FY 1989 BUDGET: $4.9 M

CSTI 88-019


PRECISION SEGMENTED REFLECTORS
ADVANCED PRECISION
SEGMENTED REFLECTOR
STRUCTURE
RS88-554(3)

HIGH CAPACITY POWER

OBJECTIVE:

DEVELOP THE TECHNOLOGY BASE NEEDED TO MEET THE LONG DURATION, HIGH CAPACITY POWER REQUIREMENTS FOR FUTURE NASA SPACE INITIATIVES

- INCREASE SYSTEM THERMAL ELECTRICAL ENERGY CONVERSION EFFICIENCY AT LEAST FIVEFOLD
- ACHIEVE SYSTEMS COMPATIBLE WITH SPACE NUCLEAR REACTORS

APPROACH:

EXPERIMENTAL VERIFICATION OF ADVANCED ENERGY CONVERSION TECHNOLOGIES, SUCH AS THE FREE-PISTON STIRLING ENGINE AND HIGH EFFICIENCY THERMOELECTRIC MATERIALS

HIGH CAPACITY POWER

OAST CSTI

MANAGEMENT

- LEAD OAST DIVISION

  PROPULSION, POWER, AND ENERGY DIVISION

- LEAD NASA FIELD CENTER

  LEWIS RESEARCH CENTER

- PARTICIPATING CENTER

  JET PROPULSION LABORATORY

- FY 1989 BUDGET: $ 11.1 M

CSTI 88-019

HIGH CAPACITY POWER

CSTI PROGRAM BUDGET

ELEMENTS	FY 88	FY89	PLANNED FY 90-94
ROBOTICS	13.0	13.8	80
AUTONOMOUS SYSTEMS	12.1	12.1	70
EARTH-TO-ORBIT	15.8	29.1	160
BOOSTER TECHNOLOGY	8.0	9.0	20
AEROASSIST FLIGHT EXP.	15.0	13.3	150
SCIENCE SENSOR TECHNOLOGY	7.8	7.8	40
DATA: HIGH RATE/CAPACITY	8.7	8.1	30
CONTROL OF FLEX. STRUCTURES	17.1	15.7	100
PRECISION SEG. REFLECTORS	4.9	4.9	10
HIGH CAPACITY POWER	12.8	11.1	40
PROGRAM TOTALS	115.2	121.8	700

TECHNOLOGY TRANSFER TO THE USER

OAST — CSTI

- INCLUDE NASA USER REPRESENTATIVES IN

  ADVISORY GROUPS

  WORKING GROUPS

- INCLUDE INDUSTRY AND UNIVERSITY REPRESENTATIVES AS APPROPRIATE

- DISSEMINATE INFORMATION TO SPACE COMMUNITY VIA

  REPORTS

  PAPERS

  PRESENTATIONS

CSTI 88-019

Office of
Aeronautics and
Space
Technology

NASA

PATHFINDER

Technology for NASA Future Missions
an AIAA/NASA OAST Conference

September 12-13, 1988
The Capital Hilton
Washington, DC

WAYNE R. HUDSON
JOHN MANKINS
JOHN L ANDERSON

SPACE R&T STRATEGY

OAST

REVITALIZE TECHNOLOGY FOR LOW EARTH ORBIT APPLICATIONS

$\boxed{\text{DEVELOP TECHNOLOGY FOR EXPLORATION OF THE SOLAR SYSTEM}}$

MAINTAIN FUNDAMENTAL R&T BASE

BROADEN PARTICIPATION OF UNIVERSITIES

EXTEND TECHNOLOGY DEVELOPMENT TO IN-SPACE EXPERIMENTATION

FACILITATE TECHNOLOGY TRANSFER TO USERS

PATHFINDER PHILOSOPHY

OAST

PROVIDE A BROAD RANGE OF TECHNOLOGY OPTIONS FOR ROBOTIC AND HUMAN EXPLORATION OF THE SOLAR SYSTEM

SUPPORT A NATIONAL DECISION ON THE EXPLORATION PATHWAY IN THE EARLY 1990'S

PRODUCE CRITICAL TECHNOLOGY DELIVERABLES IN SUPPORT OF CHOSEN MISSION SCENARIO IN MID TO LATE 90'S

MAJOR TECHNOLOGY DEMONSTRATIONS ADDED WHEN PATHWAY DECISION IS MADE

KEEP TECHNOLOGY AS AN ACTIVE PARTICIPANT IN AGENCY PLANNING PROCESS

PATHFINDER STATUS

OAST

APPROVED FY1989 NEW START

PROGRAM AND PROJECT PLANS CURRENTLY BEING WRITTEN

PROGRAM ELEMENTS DISTRIBUTED AMONG NASA CENTERS

SOME ELEMENTS WILL BE DEFERED IN FY1989, BUT ALL ELEMENTS WILL BE KEPT IN OUT YEAR PROGRAM

BUDGET STARTS AT $40M IN FY89, IS PLANNED TO INCREASE TO $220M LEVEL BY FY92 AND CONTINUE OUT INTO 1990'S.

OAST

OFFICE OF EXPLORATION CASE STUDIES

HUMAN EXPEDITION TO PHOBOS

HUMAN EXPEDITIONS TO MARS

LUNAR OBSERVATORIES

LUNAR OUTPOST TO EARLY MARS OUTPOST

PATHFINDER THRUSTS AND ELEMENTS

MISSION STUDIES

EXPLORATION

PLANETARY ROVER
SAMPLE ACQUISTION,ANALYSIS &PRESERVATION
SURFACE POWER
OPTICAL COMMUNICATIONS

HUMANS-IN-SPACE

EVA/SUIT
HUMANPERFORMANCE
CLOSED-LOOP LIFE SUPPORT

TRANSFER VEHICLES

CHEMICAL TRANSFER PROPULSION
CARGO VEHICLE PROPULSION
HIGH ENERGY AEROBRAKING
AUTONOMOUS LANDER
FAULT-TOLERANT SYSTEMS

OPERATIONS

AUTONOMOUS RENDEZVOUS AND DOCKING
RESOURCE PROCESSING PILOT PLANT
IN-SPACE ASSEMBLY & CONSTRUCTION
CRYOGENIC FLUID DEPOT
SPACE NUCLEAR POWER (SP100)

Office of
Aeronautics and
Space
Technology

NASA

PATHFINDER

SURFACE EXPLORATION, IN-SPACE OPERATIONS, AND SPACE TRANSFER

Technology for NASA Future Missions
an AIAA/NASA OAST Conference

September 12-13, 1988
The Capital Hilton
Washington, DC

JOHN MANKINS
PATHFINDER PROGRAM MANAGER

PATHFINDER PROGRAM AREA
SURFACE EXPLORATION

OAST

TECHNOLOGY NEEDS

- PILOTED AND AUTOMATED SURFACE MOBILITY AND MANIPULATION SYSTEMS
- MOBILE AND STATIONARY SURFACE POWER SYSTEMS (SOURCES AND STORAGE)
- ADVANCED SPACE COMPUTING, WITH GROUND & ON-BOARD AUTONOMOUS SYSTEMS
- MULTIPLE SENSORS (REMOTE AND LOCAL)
- SURFACE MATERIALS, STRUCTURES, AND MECHANISMS
- TECHNOLOGIES FOR SURFACE SCIENCES (E.G., SAMPLING AND IN SITU ANALYSIS)

JCM-0750

PATHFINDER PROGRAM AREA
SURFACE EXPLORATION

OAST

ELEMENT PROGRAMS

- PLANETARY ROVER
- SAMPLE ACQUISITION, ANALYSIS, & PRESERVATION
- AUTONOMOUS LANDER
- SURFACE POWER
- PHOTONICS

JCM-0745

PATHFINDER
PLANETARY ROVER

TECHNOLOGIES

- MOBILITY
- AUTONOMOUS GUIDANCE
- SAMPLING ROBOTICS
- ROVER POWER

MISSION APPLICATIONS

- LUNAR ROVERS (Piloted & Robotic)
- MARS ROVERS (Piloted & Robotic)
- OTHER ROBOTIC EXPLORATION AND SAMPLE RETURN MISSIONS (e.g., CNSR)

JCM-0053

PATHFINDER
PLANETARY ROVER

OAST

PROGRAM MANAGEMENT

- **LEAD OAST DIVISION:**
  Information Sciences And Human Factors Division

- **LEAD NASA FIELD CENTER:**
  Jet Propulsion Laboratory

- **PARTICIPATING CENTERS:**
  Ames Research Center
  Langley Research Center
  Lewis Research Center

- **FY 1989 BUDGET: $ 5 MILLION**

JCM-0758

PATHFINDER
SAMPLE ACQUISITION, ANALYSIS & PRESERVATION

OAST

TECHNOLOGIES

- SAMPLING TOOLS & SYSTEMS
- CHEMICAL/PHYSICAL ANALYSIS SENSORS
- PRESERVATION (e.g., Materials, Seals)

MISSION APPLICATIONS

- LUNAR ROVERS (Piloted & Robotic)
- MARS ROVERS (Piloted & Robotic)
- OTHER SAMPLE RETURN MISSIONS (CNSR)

JCM-0054

PATHFINDER
SAMPLE ACQUISITION, ANALYSIS, & PRESERVATION

OAST

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Materials and Structures Division

- LEAD NASA FIELD CENTER:
  Jet Propulsion Laboratory

- PARTICIPATING CENTERS:
  Ames Research Center
  Johnson Space Center

- FY 1989 BUDGET: $ 1 MILLION

JCM-0759

PATHFINDER
AUTONOMOUS LANDER

OAST

TECHNOLOGIES

- GN&C (Terminal Descent)
- SENSORS
- SYSTEMS AUTONOMY
- MECHANIZATION/MECHANICAL SYSTEMS

MISSION APPLICATIONS

- LUNAR OUTPOST OPERATIONS VEHICLES
- ROBOTIC SOLAR SYSTEM EXPLORATION
- PILOTED MARS EXPEDITION

JCM-0069

PATHFINDER
AUTONOMOUS LANDER

OAST

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Information Sciences & Human Factors Division
- LEAD NASA FIELD CENTER:
  Johnson Space Center
- PARTICIPATING CENTERS:
  Ames Research Center
  Jet Propulsion Laboratory
- FY 1989 BUDGET: $ 1 MILLION

JCM-0760

PATHFINDER SURFACE POWER

TECHNOLOGIES

- ADVANCED PHOTOVOLTAICS
- POWER STORAGE (e.g, Fuel Cells)
- ENVIRONMENTAL COUNTERMEASURES

MISSION APPLICATIONS

- LUNAR OUTPOST START-UP
- PILOTED MARS EXPEDITIONS
- OTHER SPACECRAFT (Earth-orbit, Transfer)

JCM-0055

PATHFINDER
SURFACE POWER

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Propulsion, Power, and Energy Division
- LEAD NASA FIELD CENTER:
  Lewis Research Center
- PARTICIPATING CENTERS:
  Jet Propulsion Laboratory
  (Not funded in FY'89)
- FY 1989 BUDGET: $1.5 MILLION

JCM-0761

PATHFINDER
PHOTONICS

TECHNOLOGIES

- FAULT-TOLERANT ELECTRONICS/
  PHOTONICS SYSTEM ARCHITECTURES
- PHOTONICS COMPONENTS
  (Sensors, Memories, Input/Output Components, Image Processing)

MISSION APPLICATIONS

- LUNAR OUTPOST SYSTEMS (e.g., Observatories)
- PILOTED PHOBOS/MARS EXPEDITIONS
- ROBOTIC SOLAR SYSTEM EXPLORATION
  (e.g., Autonomous Landers, Planetary Rovers)
- ADVANCED EARTH-ORBITING OPERATIONS

JCM-0754

PATHFINDER PHOTONICS

OAST

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Information Sciences & Human Factors Division

- PARTICIPATING CENTERS:
  Ames Research Center
  Jet Propulsion Laboratory
  Johnson Space Center
  Langley Research Center

- INITIATION DEFERRED TO 1990

JCM-0762

PATHFINDER PROGRAM AREA IN-SPACE OPERATIONS

OAST

TECHNOLOGY NEEDS

- AUTOMATED AND SEMI-AUTONOMOUS OPERATIONS (E.G., RENDEZVOUS & DOCKING)
- ASSEMBLY, CONSTRUCTION, AND TESTING OF LARGE SPACE SYSTEMS (IN ORBIT AND ON SURFACES)
- MANAGEMENT AND LONG-TERM STORAGE OF CRYOGENIC FLUIDS
- HIGH-CAPACITY POWER SYSTEMS (E.G., NUCLEAR)
- HIGH-RATE SPACE COMMUNICATIONS SYSTEMS
- IN SITU RESOURCE UTILIZATION TECHNIQUES AND HARDWARE (E.G., FUEL PRODUCTION AND MINING)

JCM-0751

PATHFINDER PROGRAM AREA IN-SPACE OPERATIONS

OAST

ELEMENT PROGRAMS

- AUTONOMOUS RENDEZVOUS & DOCKING
- IN-SPACE ASSEMBLY AND CONSTRUCTION
- CRYOGENIC FLUID DEPOT
- SPACE NUCLEAR POWER (SP-100)
- RESOURCE PROCESSING PILOT PLANT
- OPTICAL COMMUNICATIONS

JCM-0746

PATHFINDER
AUTONOMOUS RENDEZVOUS & DOCKING

OAST

TECHNOLOGIES

- SENSORS (e.g., Laser Ranging, Radars)
- GN&C (Fault-Tolerant, On-Board)
- SYSTEM AUTONOMY

MISSION APPLICATIONS

- SPACE TRANSFER VEHICLES (Earth & Lunar)
- PILOTED MARS EXPEDITION
- ROBOTIC SAMPLE RETURN MISSIONS (MRSR)

JCM-0057

PATHFINDER
AUTONOMOUS RENDEZVOUS & DOCKING

OAST

PROGRAM MANAGEMENT

- **LEAD OAST DIVISION:**
  Information Sciences & Human Factors Division
- **LEAD NASA FIELD CENTER:**
  Johnson Space Center
- **PARTICIPATING CENTERS:**
  Jet Propulsion Laboratory
  Marshall Space Flight Center
- **FY 1989 BUDGET: $1 MILLION**

JCM-0763

PATHFINDER
IN-SPACE ASSEMBLY AND CONSTRUCTION

OAST

TECHNOLOGIES

- LARGE-SCALE MANIPULATION SYSTEMS (Including highly flexible manipulators)
- JOINING TECHNIQUES (e.g., Welding)
- PRECISION STRUCTURE ALIGNMENT/ADJUSTMENT

MISSION APPLICATIONS

- LUNAR OUTPOST STAGING
- MARS MISSION STAGING (Robotic, Piloted)
- ADVANCED SPACE STATION OPERATIONS
- EARTH-ORBIT OBSERVATORY STAGING

JCM-0059

PATHFINDER
IN-SPACE ASSEMBLY & CONSTRUCTION

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Materials and Structures Division
- LEAD NASA FIELD CENTER:
  Langley Research Center
- PARTICIPATING CENTERS:
  Jet Propulsion Laboratory
  Johnson Space Center
  Marshall Space Flight Center
- FY 1989 BUDGET: $1 MILLION

JCM-0764

PATHFINDER
CRYOGENIC FLUID DEPOT

OAST

TECHNOLOGIES

- LONG-TERM CRYOGEN CONTAINMENT & MANAGEMENT
- REFRIGERATION COMPONENTS/SYSTEMS
- FLUID TRANSFER COMPONENTS/SYSTEMS

MISSION APPLICATIONS

- LUNAR OUTPOST STAGING/OPERATIONS
- MARS MISSION STAGING (Robotic, Piloted)
- ADVANCED SPACE STATION OPERATIONS
- ASTROPHYSCIS OBSERVATORY SERVICING

JCM-0060

PATHFINDER
CRYOGENIC FLUID DEPOT

PROGRAM MANAGEMENT

- **LEAD OAST DIVISION:**
  Propulsion, Power, and Energy Division
- **LEAD NASA FIELD CENTER:**
  Lewis Research Center
- **PARTICIPATING CENTERS:**
  Johnson Space Center
  Marshall Space Flight Center
- **FY 1989 BUDGET: $3 MILLION**

JCM-0765

PATHFINDER
SPACE NUCLEAR POWER (SP-100)

TECHNOLOGIES

- REFRACTORY METAL REACTOR
- FUEL PINS
- HIGH-TEMPERATURE CONTROL SYSTEM
- LIQUID-METAL THERMOELECTRIC MAGNETIC PUMP
- THERMAL-TO-ELECTRIC CONVERSION
- HEAT-PIPE HEAT-REJECTION SYSTEMS

MISSION APPLICATIONS

- LUNAR/MARS OUTPOSTS
- PILOTED MARS EXPEDITION
- ADVANCED EARTH-ORBIT OPERATIONS
- ROBOTIC SOLAR SYSTEM EXPLORATION
  (Nuclear Electric Propulsion/Power)

JCM-0061

OAST

PATHFINDER
RESOURCE PROCESSING PILOT PLANT

TECHNOLOGIES

- MATERIALS ANALYSIS SENSORS
- MECHANICAL SEPARATION/EXTRACTION
- ELECTRO-CHEMICAL SEPARATION/EXTRACTION
- ROBOTIC MATERIALS COLLECTION/HANDLING

MISSION APPLICATIONS

- LUNAR OUTPOST RESOURCE PLANT
- MARS RESOURCE PLANT
- OTHER SOLAR SYSTEM RESOURCE UTILIZATION

JCM-0058

PATHFINDER
RESOURCE PROCESSING PILOT PLANT

OAST

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Materials and Structures Division
- LEAD NASA FIELD CENTER:
  Johnson Space Center
- PARTICIPATING CENTERS:
  Jet Propulsion Laboratory
- INITIATION DEFERRED TO 1990

JCM-0767

OAST

PATHFINDER OPTICAL COMMUNICATIONS

TECHNOLOGIES

- ACQUISITION & TRACKING SYSTEMS
- CONTROL SYSTEMS
- TELESCOPE/LASER SYSTEMS

MISSION APPLICATIONS

- LUNAR OUTPOST
- PILOTED MARS EXPEDITIONS
- ROBOTIC SOLAR SYSTEM EXPLORATION

JCM-0056

PATHFINDER
OPTICAL COMMUNICATIONS

PROGRAM MANAGEMENT

- **LEAD OAST DIVISION:**
  Information Sciences & Human Factors Division

- **PARTICIPATING CENTERS:**
  Goddard Space Flight Center
  Jet Propulsion Laboratory

- **INITIATION DEFERRED TO 1990**

JCM-0768

PATHFINDER PROGRAM AREA
SPACE TRANSFER

OAST

TECHNOLOGY NEEDS

- ADVANCED CHEMICAL PROPULSION SYSTEMS (DESIGNED FOR SPACE-BASING/MAINTENANCE)
- HIGH-THRUST IN-SPACE PROPULSION FOR HUMAN MISSION STAGING
- LUNAR-LEO AND INTERPLANETARY AERO-BRAKING (TPS, GN&C, AEROTHERMODYNAMICS)
- DESCENT/ASCENT PROPULSION FOR MOON/MARS APPLICATIONS
- HIGH-EFFICIENCY ELECTRIC PROPULSION FOR CARGO TRANSFER

JCM-0752

PATHFINDER PROGRAM AREA
SPACE TRANSFER

OAST

ELEMENT PROGRAMS

- CHEMICAL TRANSFER PROPULSION
- HIGH-ENERGY AEROBRAKING
- CARGO VEHICLE PROPULSION

JCM-0748

PATHFINDER
CHEMICAL TRANSFER PROPULSION

TECHNOLOGIES

- LIQUID OXYGEN/HYDROGEN ENGINES
- HIGH-HEAT COMBUSTERS
- HIGH-PRESSURE TURBO-MACHINERY
- INTEGRATED DIAGNOSTICS/CONTROLS

MISSION APPLICATIONS

- LUNAR OUTPOST OPERATIONS VEHICLES
- ROBOTIC SOLAR SYSTEM EXPLORATION
- PILOTED MARS EXPEDITION
- ADVANCED EARTH-ORBIT OPERATIONS

JCM-0065

OAST

PATHFINDER
CHEMICAL TRANSFER PROPULSION

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Propulsion, Power, and Energy
  Division
- LEAD NASA FIELD CENTER:
  Lewis Research Center
- PARTICIPATING CENTERS:
  Marshall Space Flight Center
  (Not funded in FY'89)
- FY 1989 BUDGET: $4 MILLION

JCM-0773

PATHFINDER
HIGH-ENERGY AEROBRAKING

OAST

TECHNOLOGIES

- AEROBRAKE CONFIGURATIONS
- AEROTHERMODYNAMICS
- GN&C (On-Board, Autonomous, Adaptive)
- THERMAL PROTECTION SYSTEMS

MISSION APPLICATIONS

- LUNAR OUTPOST OPERATIONS
- ROBOTIC/PILOTED MARS EXPEDITION
- ROBOTIC SOLAR SYSTEM EXPLORATION

JCM-0067

PATHFINDER
HIGH-ENERGY AEROBRAKING

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Aerodynamics Division

- LEAD NASA FIELD CENTER:
  Langley Research Center

- PARTICIPATING CENTERS:
  Ames Research Center
  Johnson Space Center
  Jet Propulsion Laboratory

- FY 1989 BUDGET: $1.5 MILLION

JCM-0772

PATHFINDER
CARGO VEHICLE PROPULSION

OAST

TECHNOLOGIES

- MAGNETOPLASMADYNAMIC THRUSTERS (MPD) (e.g., Cathodes, Controls, Magnetic Fields, High Power Level Systems)
- ION ENGINES (Testing)
- LONG-LIFE TESTING

MISSION APPLICATIONS

- LUNAR OUTPOST OPERATIONS (OTV/Ion)
- PILOTED MARS EXPEDITION (Cargo Vehicle)
- ROBOTIC SOLAR SYSTEM EXPLORATION (Ion)

JCM-0066

PATHFINDER
CARGO VEHICLE PROPULSION

PROGRAM MANAGEMENT

- LEAD OAST DIVISION:
  Propulsion, Power, and Energy Division
- LEAD NASA FIELD CENTER:
  Lewis Research Center
- PARTICIPATING CENTERS:
  Jet Propulsion Laboratory
- INITIATION DEFERRED TO 1990

JCM-0774

PATHFINDER THRUSTS AND ELEMENTS

OAST

MISSION STUDIES

TRANSFER VEHICLES

CHEMICAL TRANSFER PROPULSION
CARGO VEHICLE PROPULSION
HIGH ENERGY AEROBRAKING
AUTONOMOUS LANDER
FAULT-TOLERANT SYSTEMS

EXPLORATION

PLANETARY ROVER
SAMPLE ACQUISTION,ANALYSIS &PRESERVATION
SURFACE POWER
OPTICAL COMMUNICATIONS

OPERATIONS

AUTONOMOUS RENDEZVOUS AND DOCKING
RESOURCE PROCESSING PILOT PLANT
IN-SPACE ASSEMBLY & CONSTRUCTION
CRYOGENIC FLUID DEPOT
SPACE NUCLEAR POWER (SP100)

HUMANS-IN-SPACE

EVA/SUIT
HUMANPERFORMANCE
CLOSED-LOOP LIFE SUPPORT

Office of
Aeronautics and
Space
Technology

NASA

PATHFINDER

HUMANS IN SPACE

Technology for NASA Future Missions
an AIAA/NASA OAST Conference

September 12-13, 1988
The Capital Hilton
Washington, DC

JOHN L ANDERSON
HUMANS IN SPACE
PROGRAM INTEGRATOR

HUMAN EXPLORATION OF THE SOLAR SYSTEM

MISSION CONDITIONS

- O DURATION INCREASE OF AN ORDER OF MAGNITUDE
- O UNACCUSTOMED ENVIRONMENTAL STRESS FROM:
  - * SMALL GROUP, CONFINED ISOLATION
  - * UNFAMILIAR RISKS
  - * SPACE RADIATION
  - * UNNATURAL GRAVITY FIELDS
- O TOTAL, UNRELIEVED DEPENDENCE ON ADVANCED TECHNOLOGICAL SYSTEMS

HUMAN EXPLORATION OF THE SOLAR SYSTEM

HUMAN SELF-SUFFICIENCY

- O ON PAST MISSIONS, FLIGHTS HAVE BEEN SHORT, ACTIVITIES NEW AND CHALLENGING, AND RESOURCES EXPENDABLE
  - * PERFORMANCE REQUIREMENTS HAVE FALLEN WITHIN EASY REACH OF HUMAN VERSATILITY AND SHORT-TERM ADAPTABILITY
  - * SUPPORT REQUIREMENTS HAVE FALLEN WITHIN OUR TRANSPORT CAPABILITY
- O BUT FOR MUCH LONGER MISSIONS:
  - * HUMANS MUST FUNCTION OUTSIDE THE BOUNDARIES OF THE CURRENTLY KNOWN PERFORMANCE ENVELOPE
  - * LIFE SUPPORT RESOURCES MUST BE REGENERATED

PATHFINDER / HUMANS IN SPACE

RATIONALE

- EXISTING TECHNOLOGIES MAY NOT BE SCALABLE TO MEET HUMAN PERFORMANCE AND SUPPORT REQUIRMENTS OVER LONG, SELF-SUFFICIENT MISSIONS

- TECHNOLOGY IDENTIFICATION AND ADVANCEMENT CANNOT EFFECTIVELY PROCEED INDEPENDENTLY FROM THE DETERMINATION OF THE HUMAN REQUIREMENTS

PATHFINDER / HUMANS IN SPACE

JOINT PROGRAM

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

OFFICE OF SPACE SCIENCE AND APPLICATIONS
(LIFE SCIENCES DIVISION)

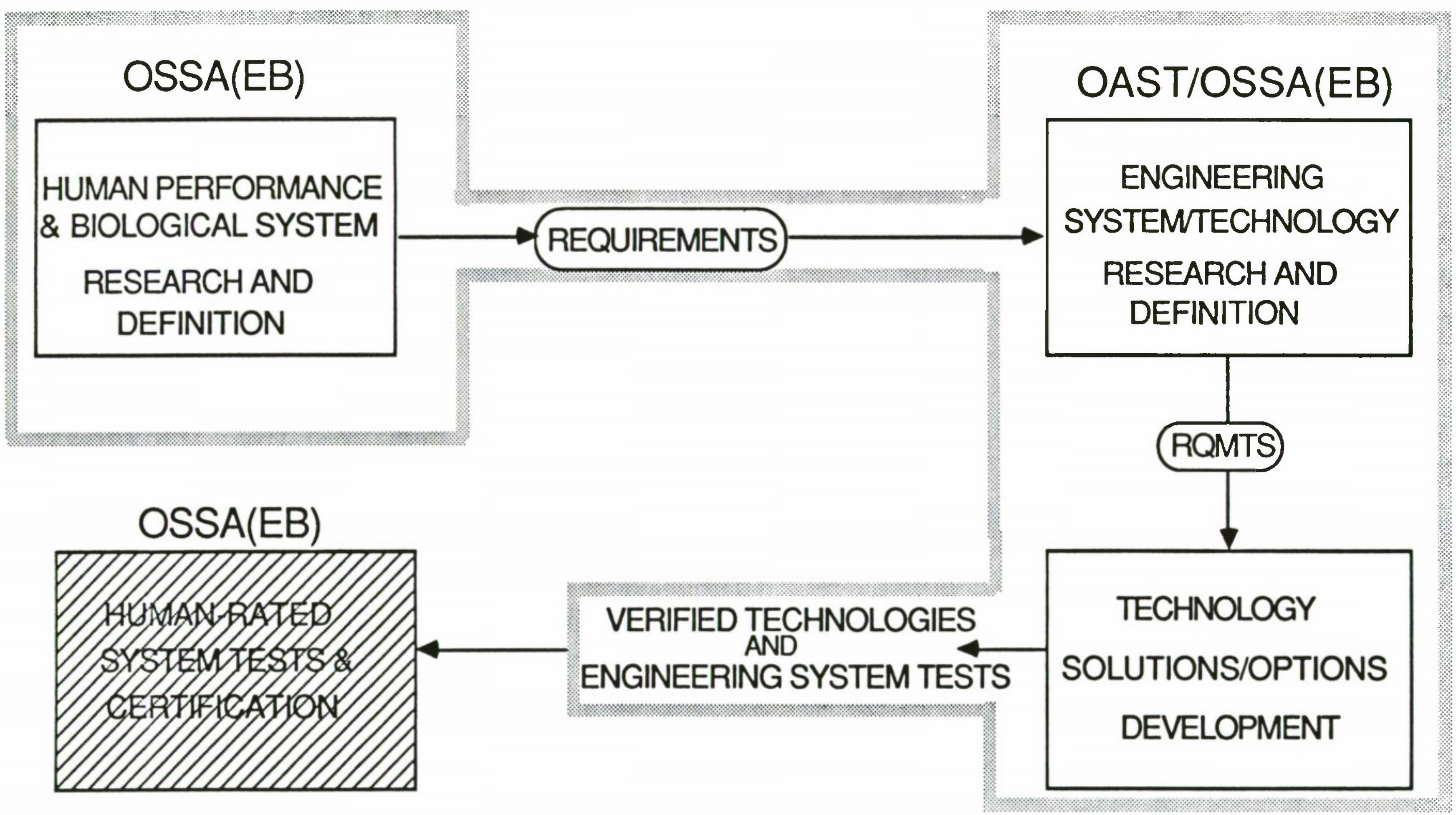
OBJECTIVES

Determine the enabling system engineering and technology requirements and develop technology options

Determine critical human and system performance requirements for enabling human health, productivity and self-sufficiency

PATHFINDER/HUMANS-IN-SPACE

TECHNICAL REQUIREMENTS INTERFACES



HUMANS IN SPACE - FUNCTIONAL OBJECTIVES

ENABLE: ON-DEMAND, EXTENDED DURATION SURFACE EVA WITH ON-SURFACE SUIT MAINTENANCE AND ECLSS REGENERATION

ENABLE: PRODUCTIVE COGNITIVE, PHYSICAL, BEHAVIORAL, AND TEAM PERFORMANCE THROUGHOUT MISSIONS OF UNACCUSTOMED ENVIRONMENTAL STRESS AND DEPENDENCE ON TECHNOLOGICAL SYSTEMS

ENABLE: A MEANS TO MAINTAIN HEALTH AND PHYSICAL CONDITIONING DURING LONG EXPOSURE TO UNNATURAL GRAVITY FIELDS AND SPACE RADIATION

ENABLE: LIFE SUPPORT SYSTEM SELF-SUFFICIENCY AND SIGNIFICANT REDUCTION IN EXPENDABLES WEIGHT & TRANSPORT REQUIREMENTS FOR MISSIONS > 1 YR

HUMANS IN SPACE - PROGRAM MILESTONES

EVA/Suit

1992

- Biomedical Rqmts Defined
- Space Serviceable EVA System Concepts Analyzed
- Critical Components Developed
- PLSS / Heat-Refrig System Proof-of-Concept Demonstrated

1996

- EVA & Serv. Syst. Components and Subsystems Validated
- Integrated Systems Technology Demonstrator Completed
- End Effector & Glove Validated

2000

- Integrated Systems Tests Completed
- Prototypes Ground-Validated

HUMANS IN SPACE - PROGRAM MILESTONES

HUMAN PERFORMANCE

HUMAN-MACHINE INTERACTIONS

1992

- Cognitive & Physical Perform. Models Developed
- Human-Machine System Design Tools Developed (CAD)
- Human-Automation-Robotics System Reqmts. Determined

1996

- Model-Based CAD Habitat Design Capability Developed
- Countermeasures for Human-Machine Performance Decrement Identified
- Human-Automation-Robotics Integrated System Test Bed Operational

2000

- Human Performance Models Scientifically Validated
- Human-Machine Interface Technology Validated
- Prototype Human-Automation-Robotics System Tests Completed

HUMANS IN SPACE - PROGRAM MILESTONES

HUMAN PERFORMANCE

ARTIFICIAL GRAVITY
HUMAN FACTORS
RADIATION

1992

Prelim. Rqmts Determ. for Art-G
- Chronic Rotation Tolerance
- Feasibility of Acute-G Loading

Partial-G Load Ground Test Facility Completed

Prelim. Shielding Rqmts for Space Radiation Defined

Analog Environ. Operational

1996

Ongoing Tests to Determine Operational and Structural Parameters of Art.-G Systems

Ongoing Tests to Determine Crew Factor and Habitability Parameters

2000

Radiation Shielding Rqmts.

Artificial Gravity Rqmts.

Habitability Rqmts.

Selection, Training, Crew Factors & Mission Rqmts.

HUMANS IN SPACE - PROGRAM MILESTONES

CLOSED LOOP
LIFE SUPPORT

PHYSICAL-CHEMICAL

1992

Chem. Process Models Compl.

Chem. Process Tests Underway

Prelim. Rqmts for Monitoring & Control Determined

1996

Proc & Subsys Models Integrated and Tech. Validated in Test Bed

Power,Thermal, Fluid Subsyst. Integration Concepts Defined

P-C Eng. System Designed

Integrated P-C / Biol. System Concepts Defined

2000

Full Scale Integrated P-C System Tests Complete

Engineering Design of Integrated P-C / Biol. System

HUMANS IN SPACE - PROGRAM MILESTONES

CLOSED LOOP
LIFE SUPPORT

BIOREGENERATIVE

1992

Feasibility of Bioregenerative Concept Demonstrated in Breadboard Facility

Analytical Process & System Models Developed

Complete Initial Studies of Human-Rated Test Facility

1996

Initial Tests Conducted in Human-Rated Test Facility

Complete Model of Integrated System Behavior & Control

Define Bioregen. System with Advanced P/C Subsystems

Define Mission-Specific Bioregen. System Concepts

2000

Integrated Bioregenerative System Tests Complete

PATHFINDER
HUMANS IN SPACE

PROGRAM MANAGEMENT

- O OAST DIVISIONS:
  - * DIRECTORATE FOR SPACE
    - * PROPULSION, POWER & ENERGY
  - * INFORMATION SCIENCES AND HUMAN FACTORS
  - * MATERIALS AND STRUCTURES

OSSA LEAD DIVISION: * LIFE SCIENCES DIVISION

- O NASA FIELD CENTERS:
  - * AMES RESEARCH CENTER
  - * JOHNSON SPACE CENTER
  - * KENNEDY SPACE CENTER

- O FY 1989 BUDGET: $6.0 M
- O FY 90-94 TOTAL BUDGET: $227.5 M

SUMMARY

- O EXPANSION OF HUMAN PRESENCE INTO THE SOLAR SYSTEM WILL REQUIRE:

  * **DETERMINATION OF HUMAN RESPONSE TO MISSION CONDITIONS**
  * **DETERMINATION OF HUMAN REQUIREMENTS FOR WELL-BEING AND PRODUCTIVITY**
  * **DEVELOPMENT AND VALIDATION OF TECHNOLOGICAL SOLUTIONS (BIOMEDICAL AND ENGINEERING) TO MEET THE HUMAN AND MISSION REQUIREMENTS**

- O PROPOSED PATHFINDER PROGRAM WILL:

  * **IDENTIFY THE MOST CRITICAL UNCERTAINTIES IN HUMAN AND TECHNOLOGICAL REQUIREMENTS**
  * **RESOLVE THEM TO THE DEGREE POSSIBLE**
  * **WHERE APPROPRIATE, DEVELOP TECHNOLOGY SOLUTIONS**

Office of
Aeronautics and
Space
Technology

SPACE RESEARCH & TECHNOLOGY BASE

Presentation to

AIAA/OAST Conference on Space Technology

Lana M. Couch
Deputy Director for Space
September 12, 1988

SPACE R&T STRATEGY

OAST

REVITALIZE TECHNOLOGY FOR LOW EARTH ORBIT APPLICATIONS

DEVELOP TECHNOLOGY FOR EXPLORATION OF THE SOLAR SYSTEM

MAINTAIN FUNDAMENTAL R&T BASE

BROADEN PARTICIPATION OF UNIVERSITIES

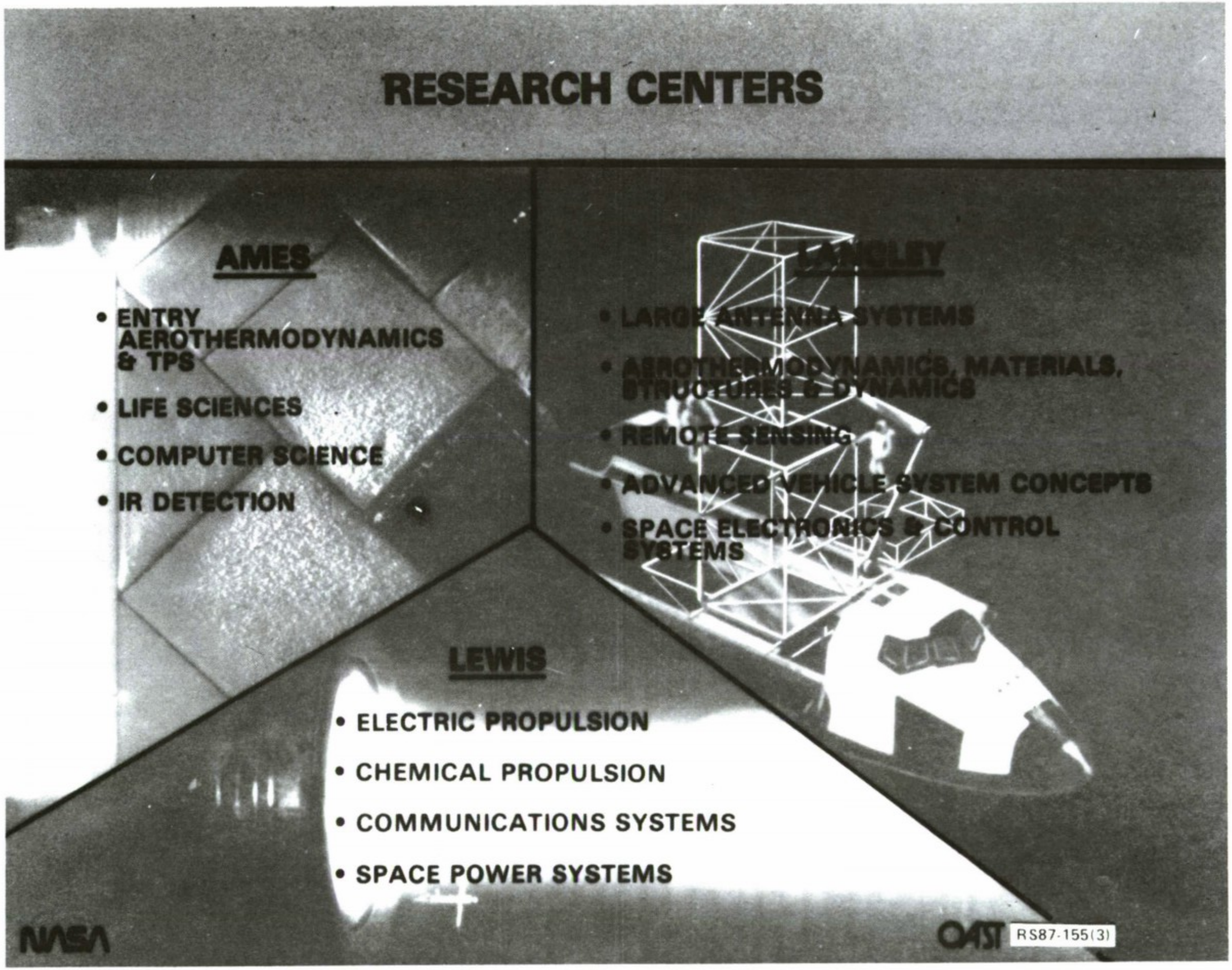
EXTEND TECHNOLOGY DEVELOPMENT TO IN-SPACE EXPERIMENTATION

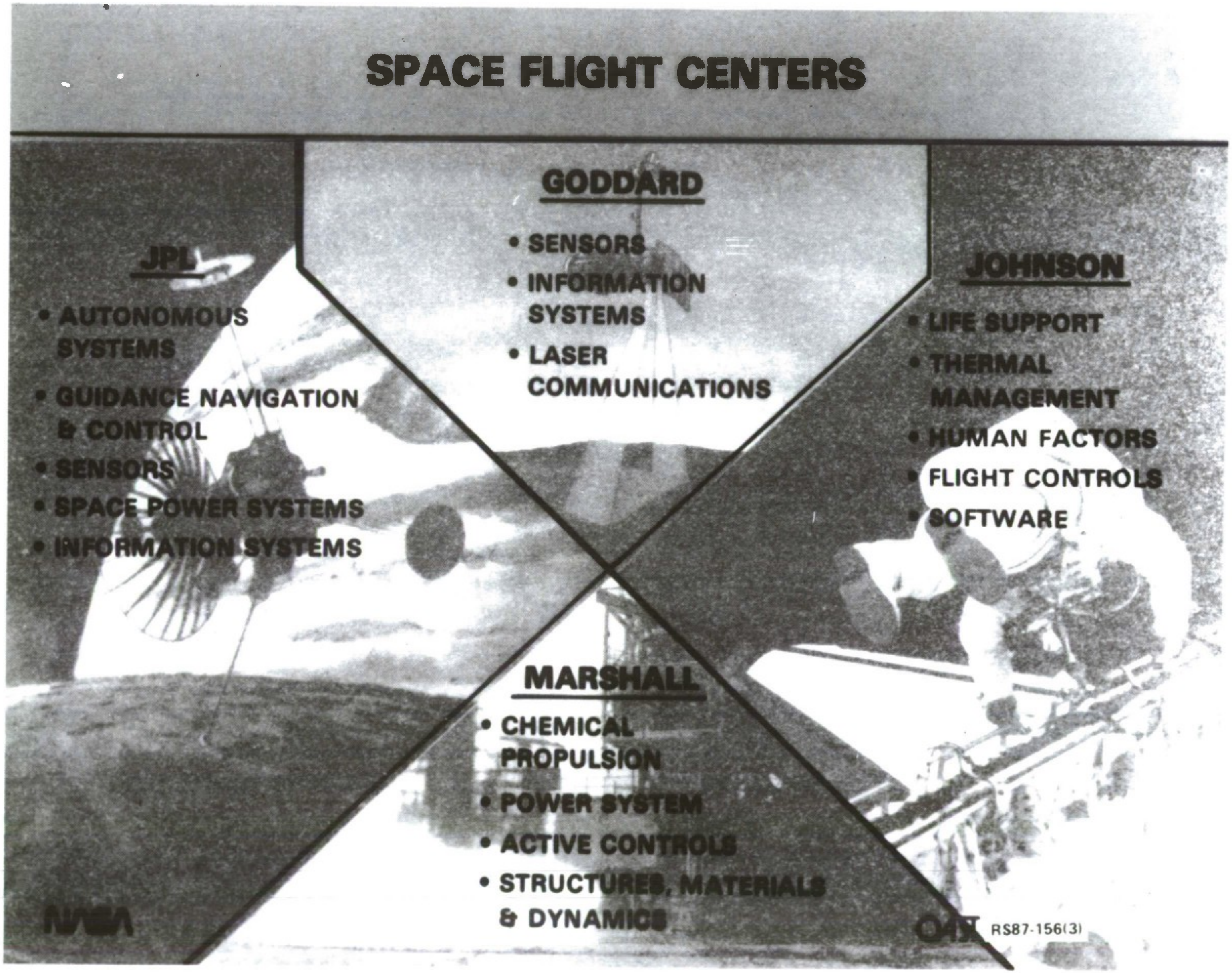
FACILITATE TECHNOLOGY TRANSFER TO USERS

OAST

R&T BASE CHARACTERISTICS

- LABORATORY RESEARCH
- GENERIC, FUNDAMENTAL
- ANALYTICAL MODELING
- ENGINEERING DATA BASE
- HIGH RISK, HIGH PAYOFF
- TECHNOLOGY OPPORTUNITIES

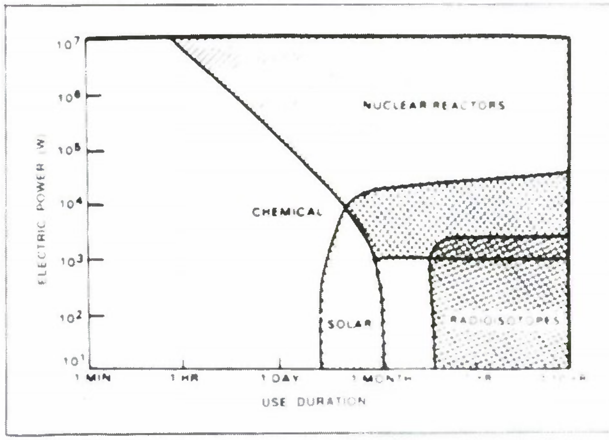

RESEARCH CENTERS
AMES
• ENTRY AEROTHERMODYNAMICS & TPS
• LIFE SCIENCES
• COMPUTER SCIENCE
• IR DETECTION
LANGLEY
• LARGE ANTENNA SYSTEMS
• AEROTHERMODYNAMICS, MATERIALS, STRUCTURES & DYNAMICS
• REMOTE SENSING
• ADVANCED VEHICLE SYSTEM CONCEPTS
• SPACE ELECTRONICS & CONTROL SYSTEMS
LEWIS
• ELECTRIC PROPULSION
• CHEMICAL PROPULSION
• COMMUNICATIONS SYSTEMS
• SPACE POWER SYSTEMS
NASA
OAST
RS87-155(3)


SPACE FLIGHT CENTERS
JPL
• AUTONOMOUS SYSTEMS
• GUIDANCE NAVIGATION & CONTROL
• SENSORS
• SPACE POWER SYSTEMS
• INFORMATION SYSTEMS
GODDARD
• SENSORS
• INFORMATION SYSTEMS
• LASER COMMUNICATIONS
JOHNSON
• LIFE SUPPORT
• THERMAL MANAGEMENT
• HUMAN FACTORS
• FLIGHT CONTROLS
• SOFTWARE
MARSHALL
• CHEMICAL PROPULSION
• POWER SYSTEM
• ACTIVE CONTROLS
• STRUCTURES, MATERIALS & DYNAMICS
NASA
OAST
RS87-156(3)

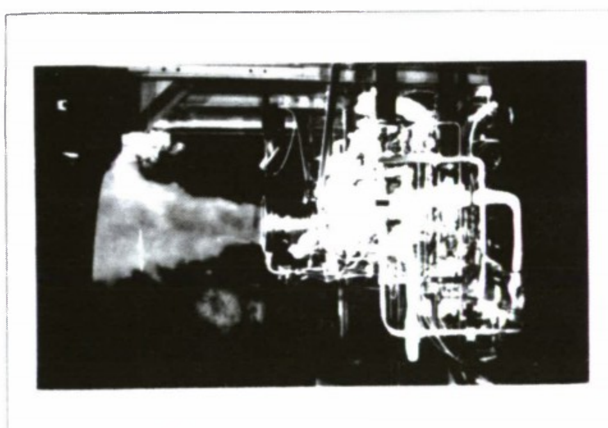
SPACE RESEARCH AND TECHNOLOGY BASE

OAST

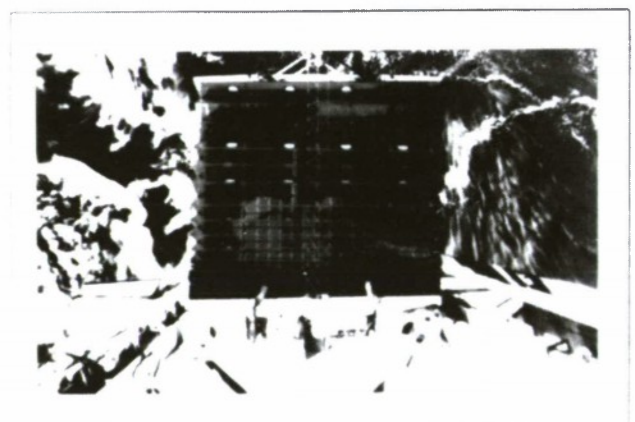
SYSTEMS ANALYSIS



UNIVERSITY PROGRAMS



DISCIPLINE RESEARCH



FLIGHT EXPERIMENTS

OAST

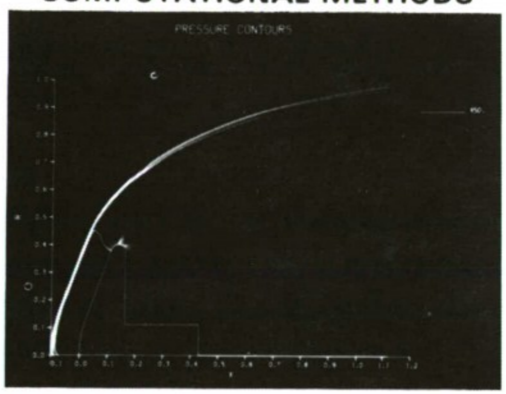
SPACE R&T

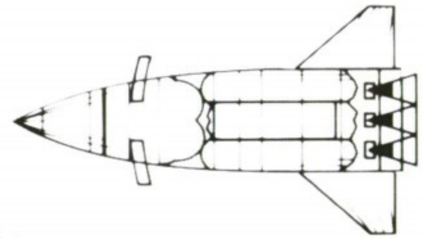
FY 1989 - $M

SPACE R&T	**295.9**
R&T BASE	**134.1**
AEROTHERMODYNAMICS R&T	11.5
SPACE ENERGY CONVERSION R&T	13.8
PROPULSION R&T	19.7
MATERIALS AND STRUCTURES R&T	17.5
SPACE DATA AND COMM. R&T	9.3
INFORMATION SCIENCES R&T	9.0
CONTROLS AND GUIDANCE R&T	6.7
HUMAN FACTORS R&T	5.3
SPACE FLIGHT R&T	18.1
SYSTEMS ANALYSIS	6.9
UNIVERSITY SPACE RESEARCH	16.3

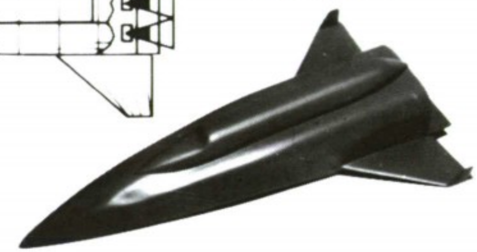
AEROTHERMODYNAMICS

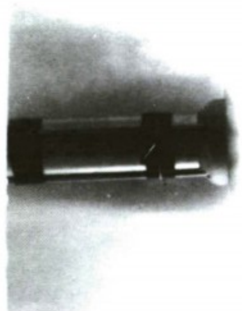
ADVANCED
COMPUTATIONAL METHODS





CONFIGURATION
ANALYSES





INTEGRATED
AEROTHERMAL
ANALYSES

HYPERSONIC
WIND
TUNNEL
TESTING

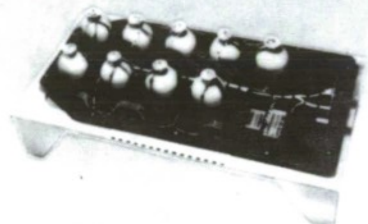
FLIGHT DATA
ANALYSES

NASA

OAST
RF88-428(3)

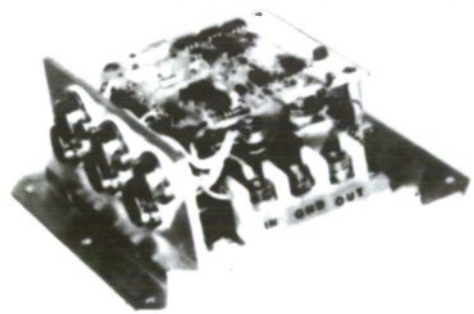
SPACE ENERGY CONVERSION

- SP-100
- SOLAR DYNAMICS



- PRIMARY/SECONDARY BATTERIES
- FUEL CELLS

- LIGHTWEIGHT ARRAYS
- CONCENTRATORS
- ADVANCED CELLS



- POWER DISTRIBUTION COMPONENTS

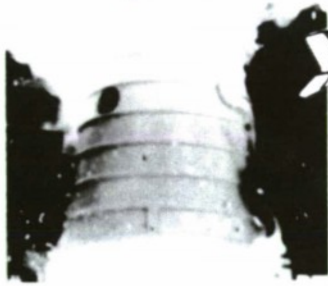
- TWO-PHASE HEAT PIPES
- ADVANCED RADIATORS

NASA

OAST
RP 85-587(3)

PROPULSION

LOX/HYDROGEN



AIRBREATHING

LOX/HYDROCARBON

REUSABLE EARTH-TO-ORBIT

ELECTRIC PROPULSION

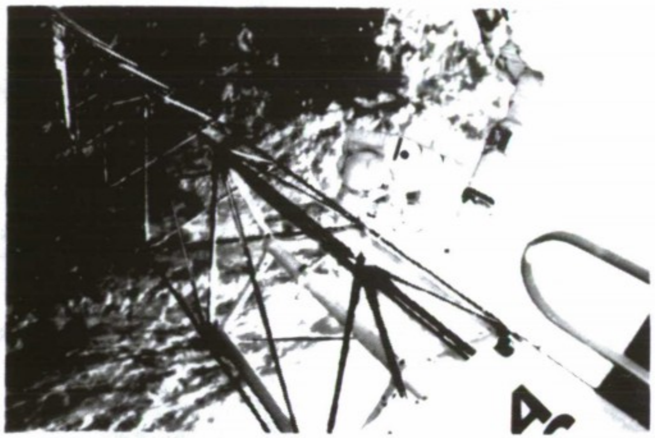
OTV PROPULSION

NASA

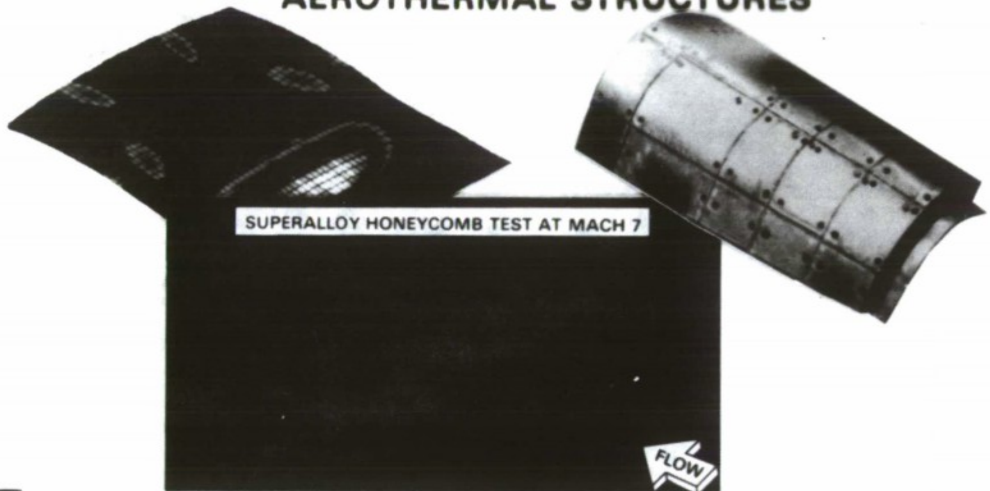
OAST
RP85-645 (3)

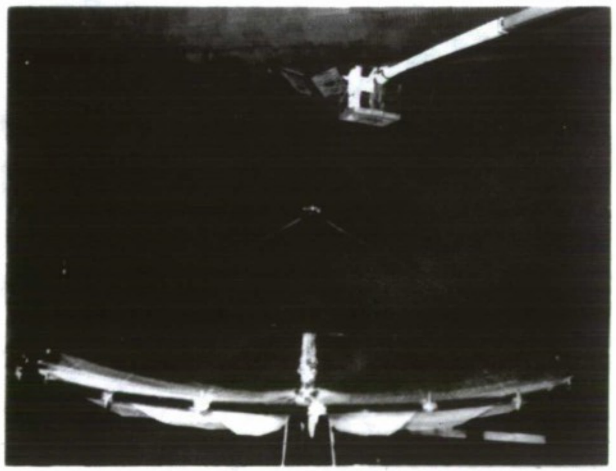
MATERIALS AND STRUCTURES

STRUCTURAL CONCEPTS

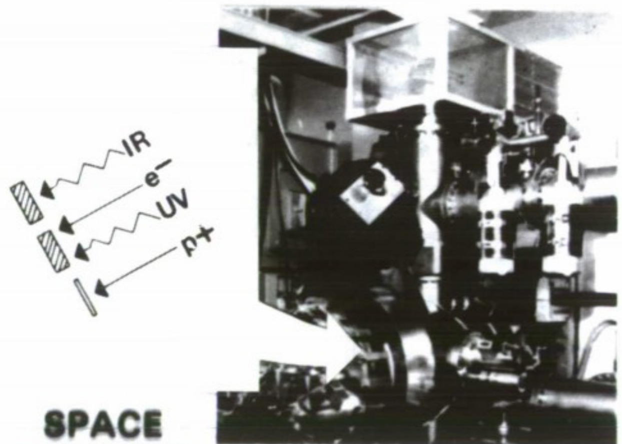


AEROTHERMAL STRUCTURES





DYNAMICS OF FLEXIBLE STRUCTURES



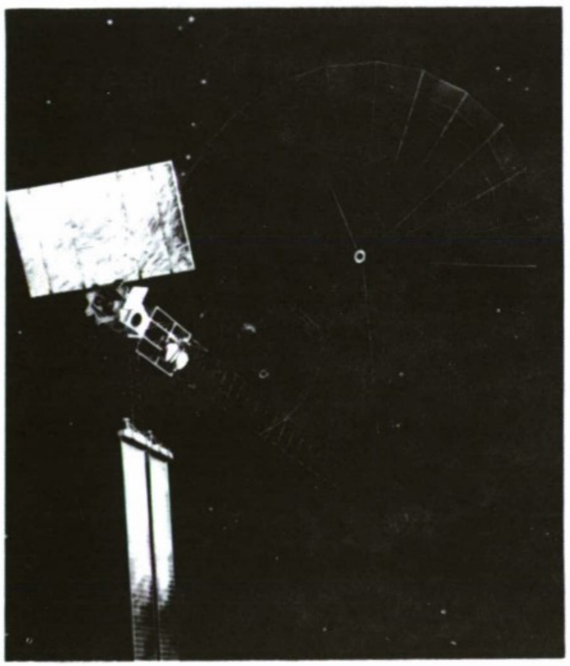
SPACE DURABLE MATERIALS

NASA

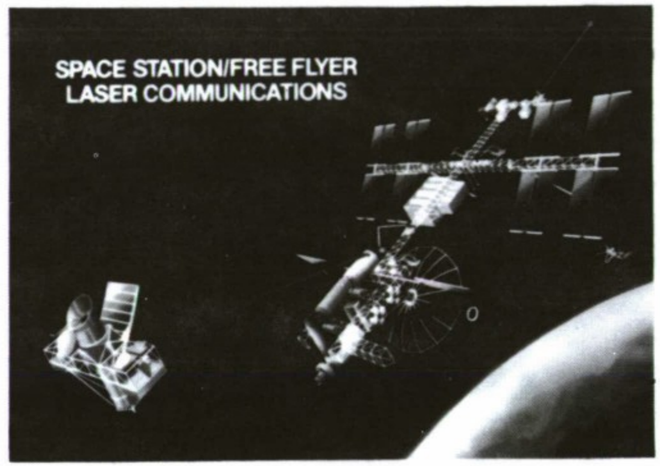
OAST
RM85-1288 (3)

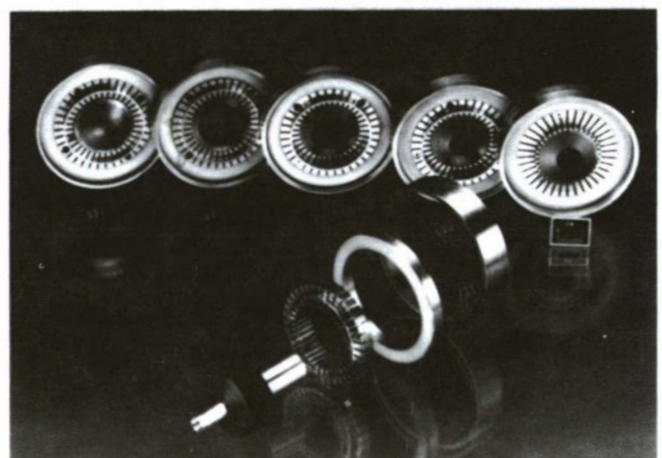
SPACE DATA AND COMMUNICATIONS

LARGE APERTURE ANTENNA



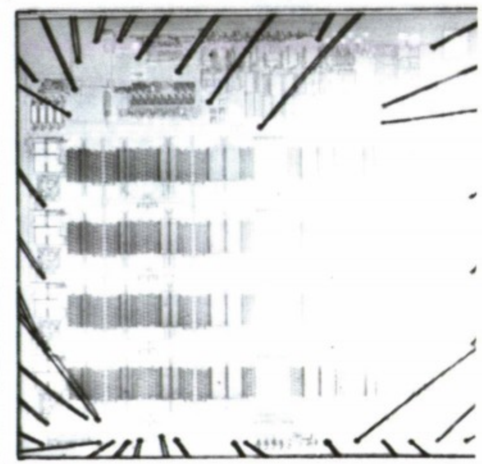
LASER COMMUNICATIONS





ADVANCED TRAVELING WAVE TUBE

ON-BOARD PROCESSING COMPONENTS

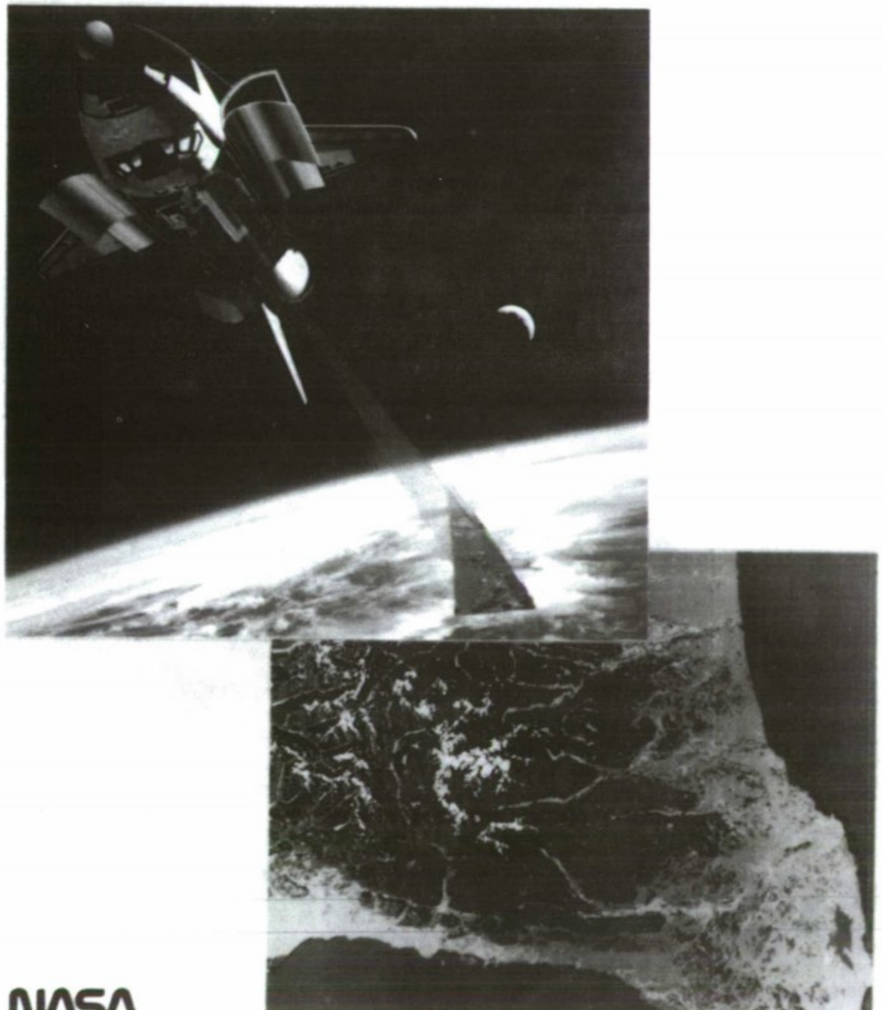


NASA

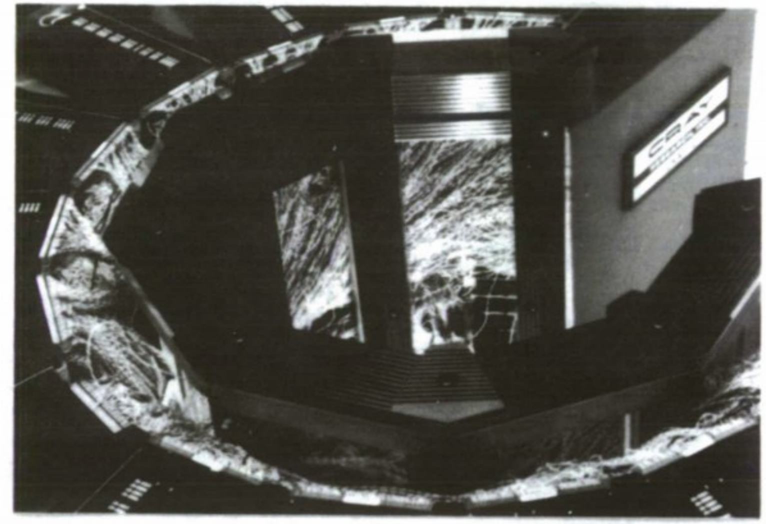
OAST
RC86-440(3)

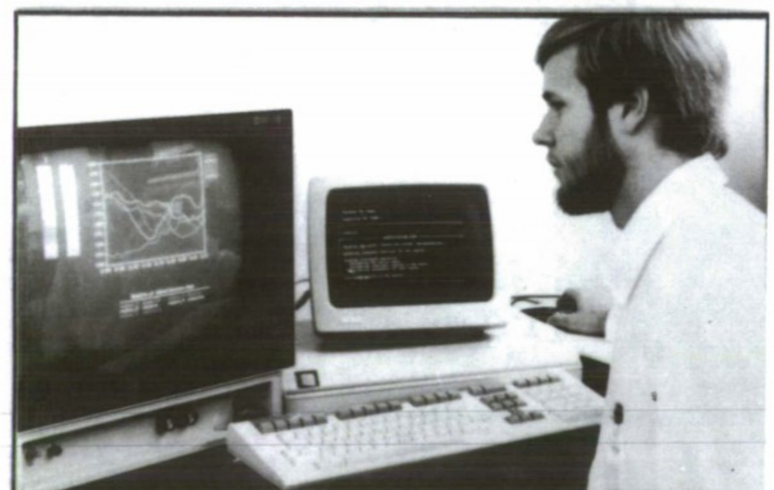
INFORMATION SCIENCES

REMOTE SENSING



COMPUTER SCIENCES





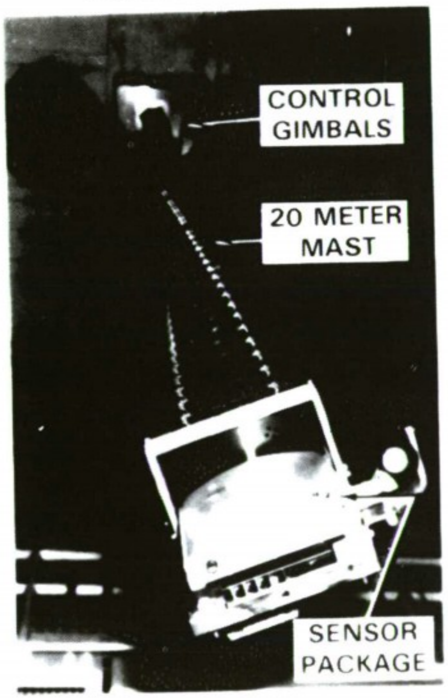
EXPERT SYSTEMS

NASA

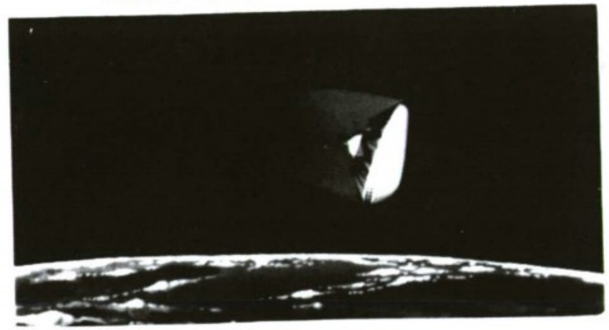
OAST
RC86-437(3)

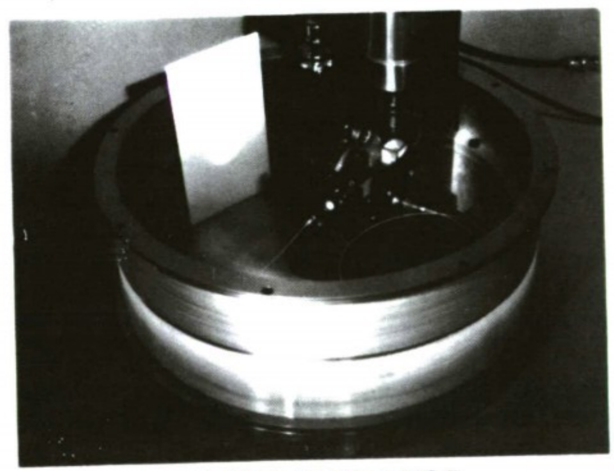
CONTROLS AND GUIDANCE

BEAM DYNAMICS



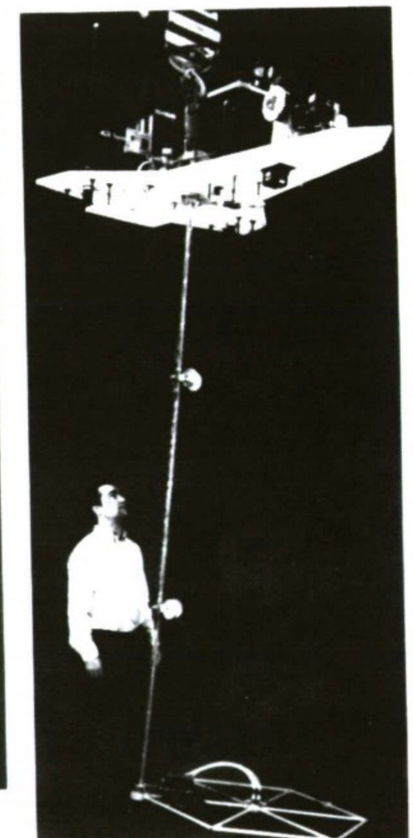
ADAPTIVE CONTROL (AFE)





LASER GUIDANCE
RESEARCH

SPACECRAFT CONTROL
LABORATORY
EXPERIMENT



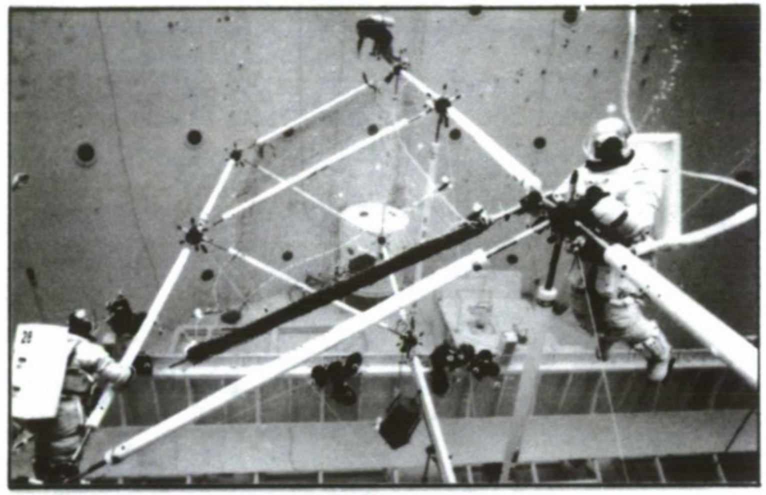
NASA

OAST
RC86-438(3)

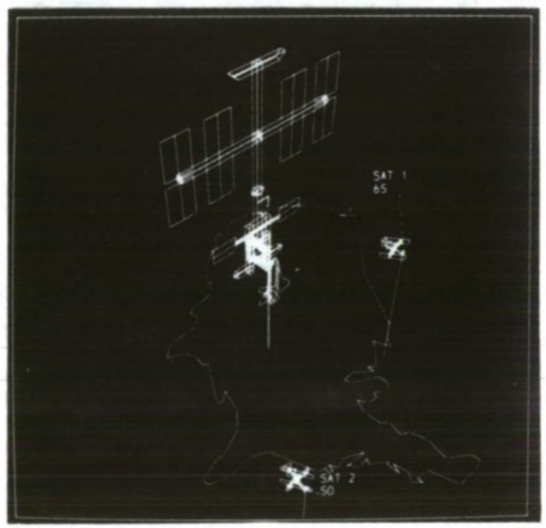
HUMAN FACTORS

SPACE SUIT

EVA AIDS



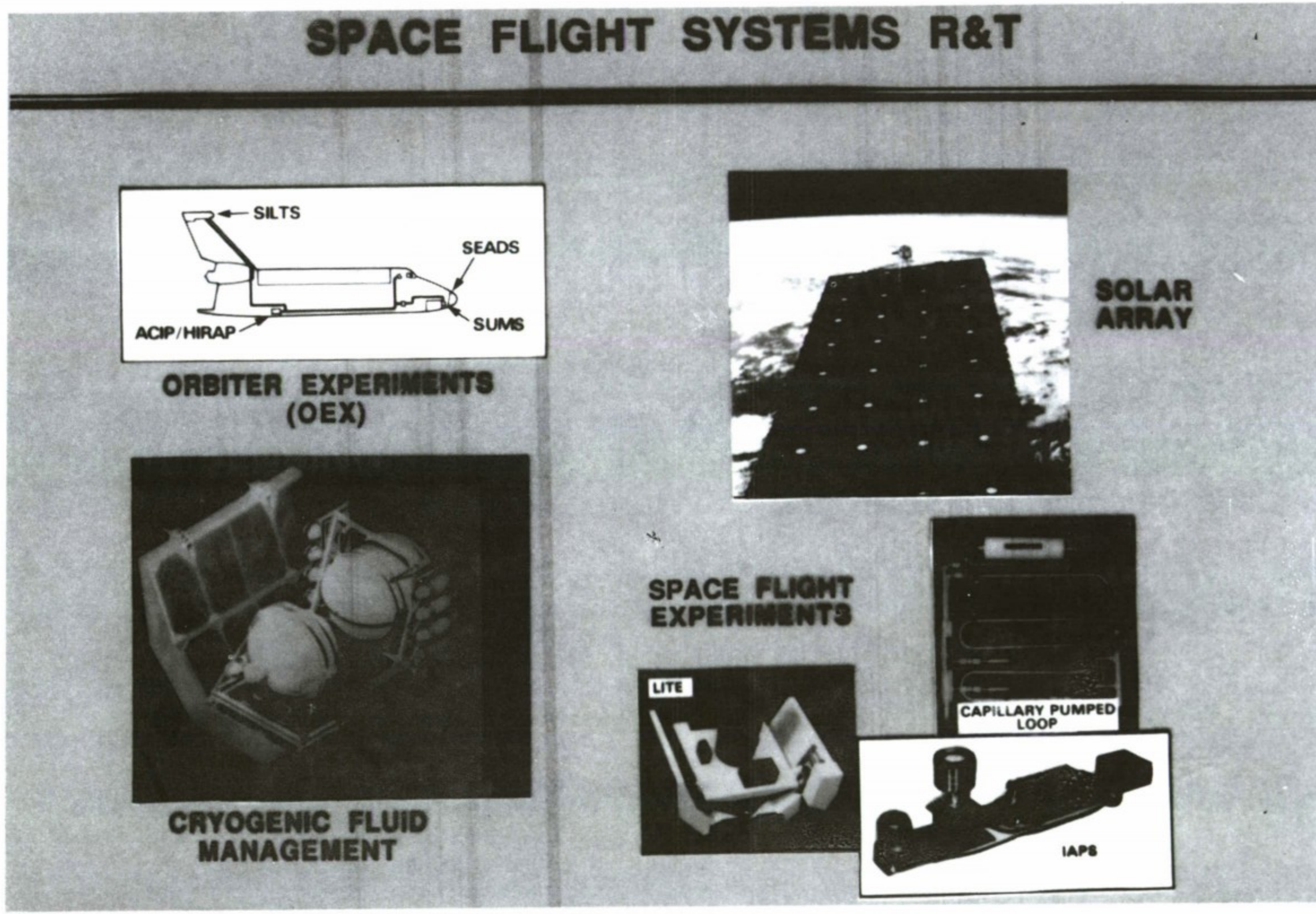
CREW STATION DESIGN



DISPLAY MODELING

NASA

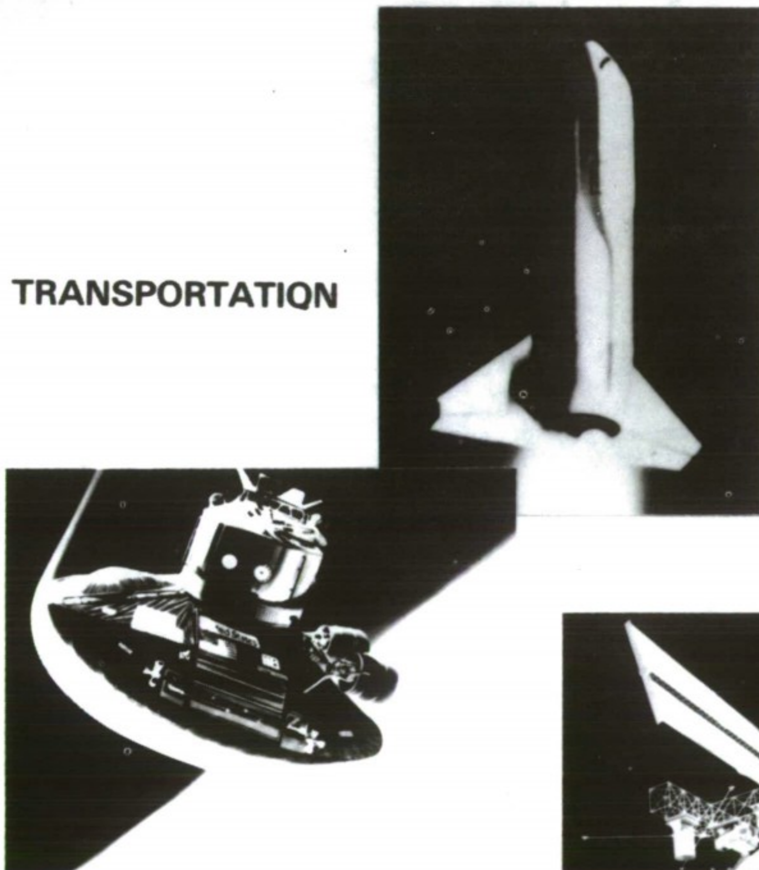
OAST
RC86-439(3)


SPACE FLIGHT SYSTEMS R&T
SILTS
SEADS
ACIP/HIRAP
SUMS
ORBITER EXPERIMENTS (OEX)
SOLAR ARRAY
CRYOGENIC FLUID MANAGEMENT
SPACE FLIGHT EXPERIMENTS
LITE
CAPILLARY PUMPED LOOP
IAPS

SYSTEMS ANALYSIS

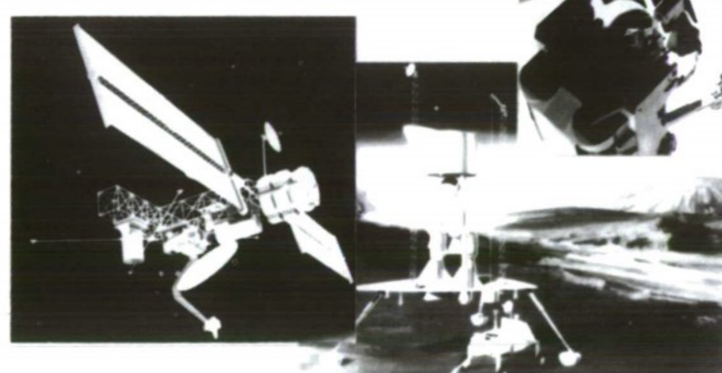
TECHNOLOGY FOR FUTURE SPACE SYSTEMS

TRANSPORTATION



LARGE SPACE SYSTEMS

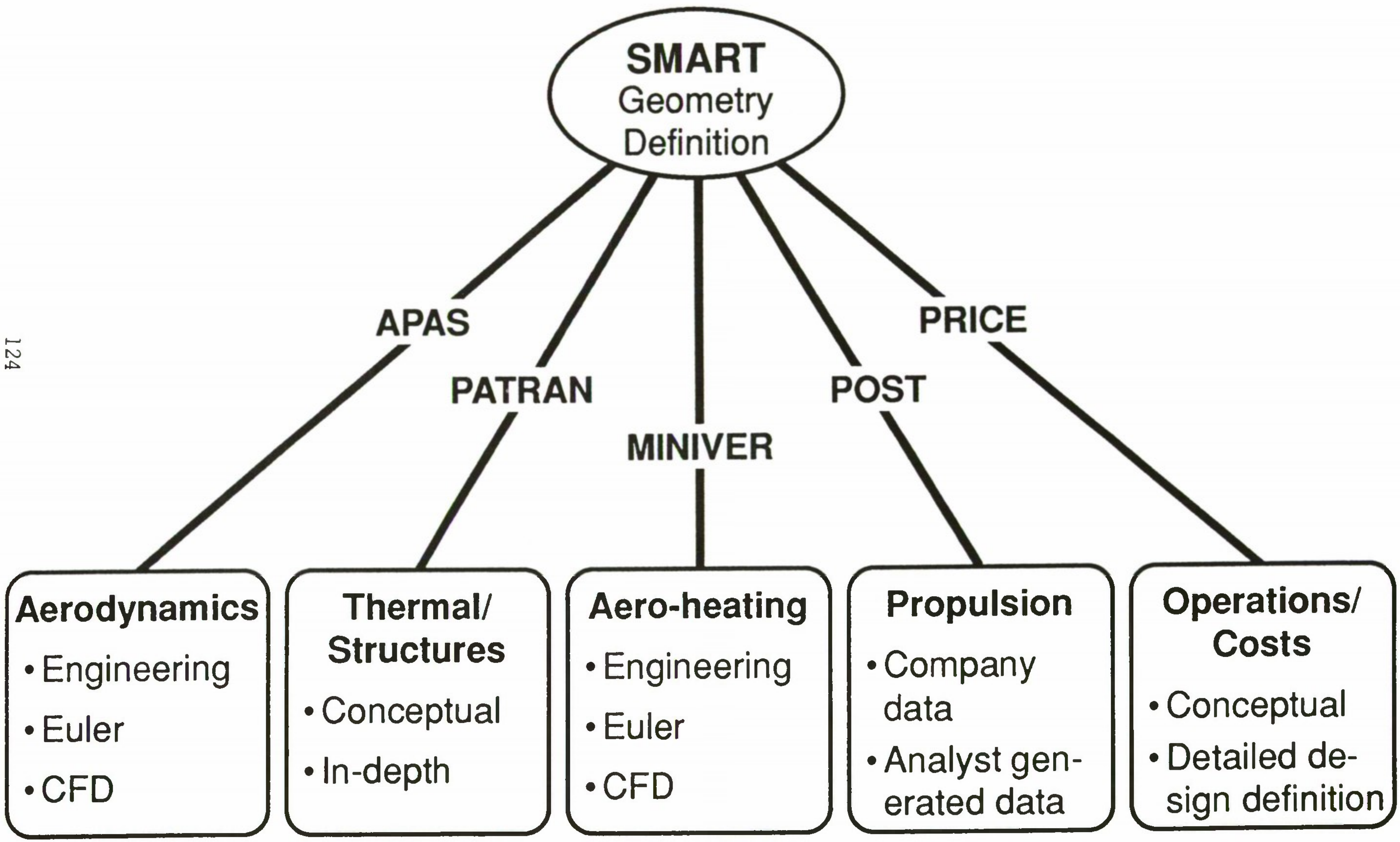
SPACECRAFT

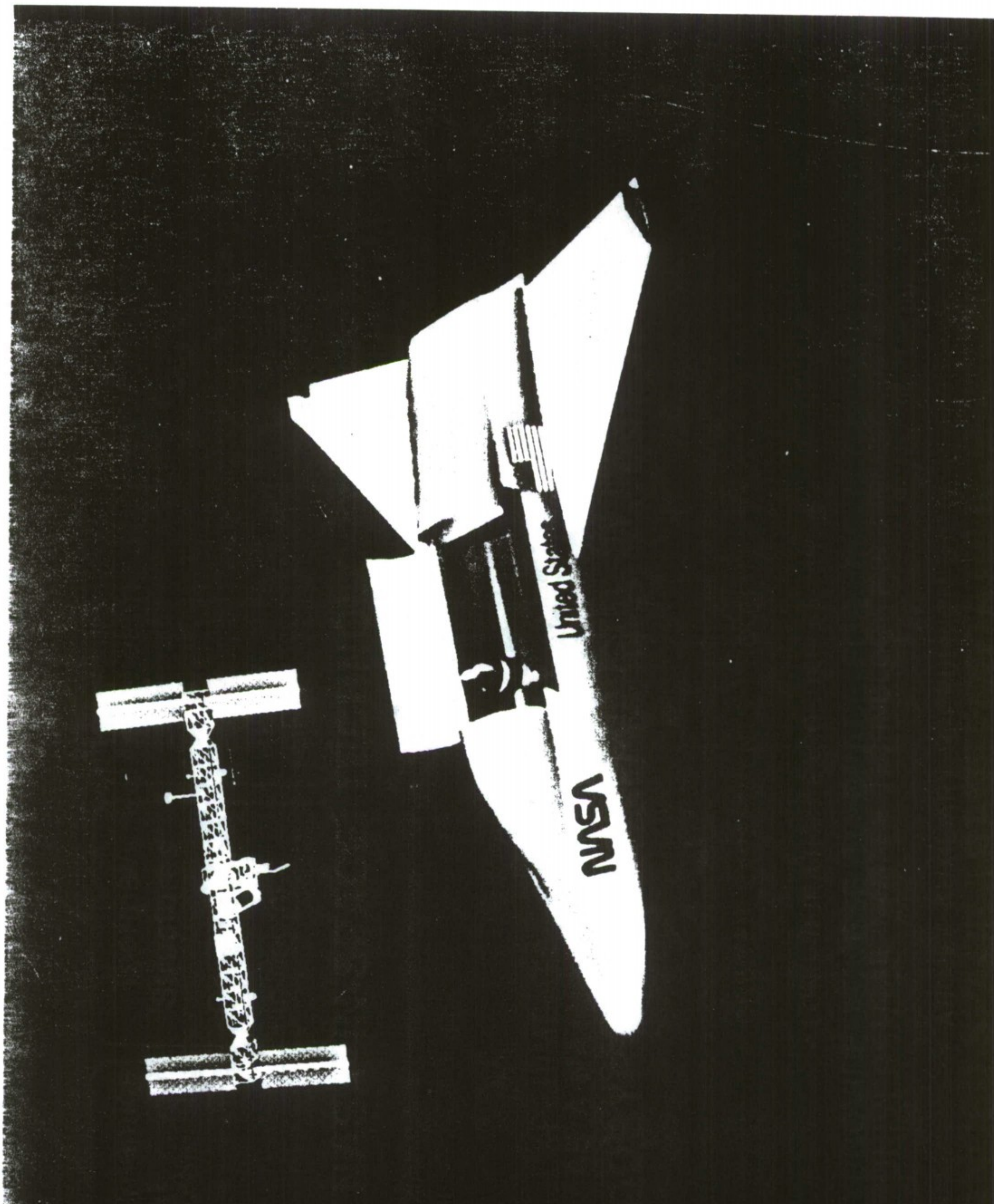


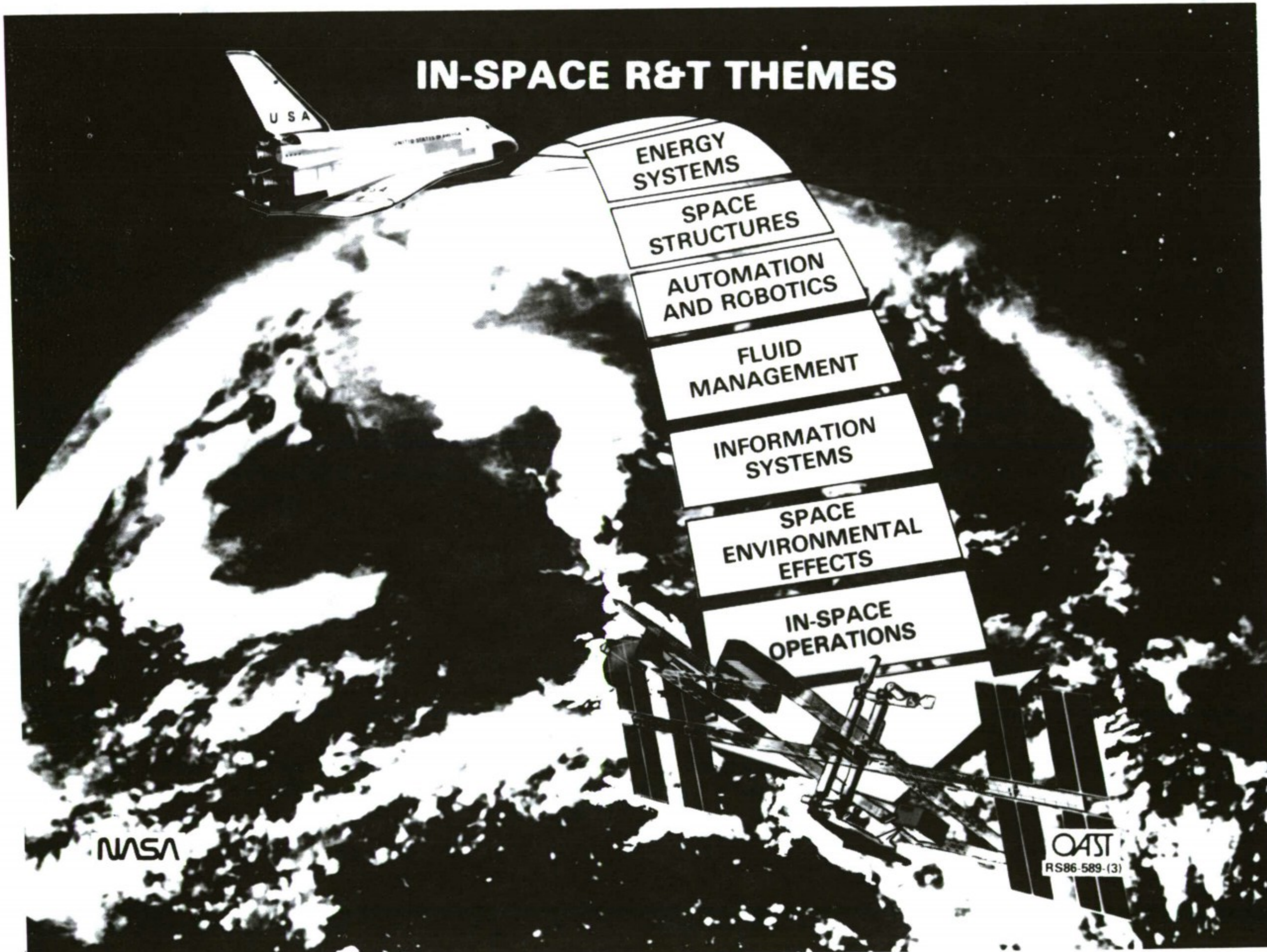
NASA

OAST
RS86-546 (3)

ADVANCED SPACE TRANSPORTATION SYSTEMS ANALYSIS




United States
NASA


IN-SPACE R&T THEMES
USA
ENERGY SYSTEMS
SPACE STRUCTURES
AUTOMATION AND ROBOTICS
FLUID MANAGEMENT
INFORMATION SYSTEMS
SPACE ENVIRONMENTAL EFFECTS
IN-SPACE OPERATIONS
NASA
OAST
RS86-589-(3)

SYSTEMS ANALYSIS STUDIES

OAST

IDENTIFY TECHNOLOGY FOR:

ADVANCED TRANSPORTATION
- SHUTTLE II
- ADVANCED LAUNCH SYSTEMS
- LUNAR/MARS VEHICLES
- TRANSPORTATION NODES

HUMAN EXPANSION
- ADVANCED SPACE STATION
- VARIABLE GRAVITY FACILITY
- LUNAR BASES
- ADVANCED POWER SYSTEMS

GLOBAL CHANGE TECHNOLOGY
- GEO SCIENCE PLATFORMS
- LEO EOS

INNOVATIVE CONCEPTS
- EXTRA-SOLAR PLANET DETECTION
- OPTICAL INTERFEROMETRY
- MICRO-SPACECRAFT
- TETHER SYSTEMS
- DESIGNS FROM NATURE
- SUPERCONDUCTORS

GIJ-0041A

SPACE RESEARCH & TECHNOLOGY BASE

OAST

INCREASED EMPHASIS FOR FUTURE

- SOFTWARE ENGINEERING
- HIGH TEMPERATURE SUPERCONDUCTORS
- OPTICS
- COMPUTATIONAL CONTROLS
- NDE/NDI
- TECHNOLOGY FOR SELF REPAIR
- BASIC RESEARCH IN "INHERENT RELIABILITY"
- MICROSAT TECHNOLOGY
- WORLD MODELING DATA SYSTEMS

GIJ-0030A

SPACE RESEARCH & TECHNOLOGY BASE
CANDIDATE EXAMPLES FOR FUTURE EMPHASIS

OAST

• SOFTWARE ENGINEERING	Objective is to develop methods, technologies, and skills to enable NASA to cost-effectively specify, build, and manage reliable complex software which is evolvable and maintainable over and extended period of time.
• HIGH TEMPERATURE SUPERCONDUCTORS	Objective is to study the suitability in the space environment of the new and rapidly evolving class of high temperature superconducting materials to a variety of space applications including sensors, processors, power, and propulsion.
• OPTICS	Objective is to enhance the on-going (CSTI and R&T Base) effort in sensors, communications, large space structures, and precision segmented reflectors with a complementary program in optics. Included are improvements in optical performance, adaptive optics, distributed apertures, and enhanced modeling capability.
• COMPUTATIONAL CONTROLS	Objective is to enhance the proceedure, tools, and theories used by space system designers to improve control system evaluation time by a factor of 40. Currently evaluation of control system performance is the limiting factor in option/trade studies and annomally response.
• NDE/NDI	Objective is to enhance the capability to inspect, monitor, evaluate, and validate space materials and structures both pre- and in-flight in order to assure a very high level of initial and continued reliability.
• TECHNOLOGY FOR SELF REPAIR	Objective is to develop self-diagnostic capabilities extending to the ability to select alternative modes of operating and/or to substitute back-up components/equipment. Efforts will include fault compensating architectures for data processors and power integrated circuits, as well as monitoring and control approaches for other spacecrft subsystems such as power and attitude control.
• BASIC RESEARCH IN "INHERENT RELIABILITY"	Objective is to conduct studies and evaluations seeking break-throughs in inherent reliability on the order of the reliability of transistors over vacuum tubes. For example, the power integrated circuit (PIC) promises to produce power systems with the reliability and reduced parts counts associated with conventional integrated circuits.
• MICROSAT TECHNOLOGY	Objective is to evaluate the technologies needed for micro-spacecraft (5 to 10 kg) that are high g-force tolerant. These spacecraft could be launched using chemical propulsion or a rail-gun launcher and used for science missions including solar system exploration.
• WORLD MODELING DATA SYSTEMS	Objective is to develop the on-board capability to store, analyze, and compare global models of the earth with spacecraft sensor data. This effort complements the Software Engineering activity and builds upon the CSTI on-board data processing and storage efforts.

GIJ-0030B

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

GOAL:

BROADEN INVOLVEMENT IN SPACE ENGINEERING AND STIMULATE INNOVATION IN TECHNOLOGY

OBJECTIVES:

- BUILD ENGINEERING SPECIALTIES
- STIMULATE CROSS-DISCIPLINE RESEARCH
- PROVIDE ENVIRONMENT FOR GENERATION OF INNOVATIVE CONCEPTS
- INCREASE NUMBER OF U.S. GRADUATES
- SUSTAINED LONG-TERM COMMITMENT

Office of
Aeronautics and
Space
Technology

IN-SPACE TECHNOLOGY EXPERIMENTS PROGRAM

InSTEP

DR. JUDITH H. AMBRUS
ASSISTANT DIRECTOR FOR SPACE,
LARGE SPACE SYSTEMS

SPACE R&T STRATEGY

OAST

REVITALIZE TECHNOLOGY FOR LOW EARTH ORBIT APPLICATIONS

DEVELOP TECHNOLOGY FOR EXPLORATION OF THE SOLAR SYSTEM

MAINTAIN FUNDAMENTAL R&T BASE

BROADEN PARTICIPATION OF UNIVERSITIES

EXTEND TECHNOLOGY DEVELOPMENT TO IN-SPACE EXPERIMENTATION

FACILITATE TECHNOLOGY TRANSFER TO USERS

IN-SPACE EXPERIMENTS IN OAST

- IN-SPACE EXPERIMENTS HAVE ALWAYS BEEN PART OF OAST'S PROGRAM

    - TO OBTAIN DATA THAT CAN NOT BE ACQUIRED ON THE GROUND
    - TO DEMONSTRATE FEASIBILITY OF CERTAIN ADVANCED TECHNOLOGIES

- CONDUCTING TECHNOLOGY EXPERIMENTSS IN SPACE IS A VALUABLEE AND COST EFFECTIVE WAY TO INTRODUCE ADVANCED TECHNOLOGY INTO FLIGHT PROGRAMS

- THE SHUTTLE HAS DEMONSTRATED THE FEASIBILITY AND TIMELY BENEFITS OF CONDUCTING HANDS-ON EXPERIMENTS IN SPACE

- SPACE STATION WILL BE A PERMANENT LABORATORY IN SPACE AND WILL PROVIDE LOGICAL AND EVOLUTIONARY EXTENSION OF GROUND BASED R&T IN SPACE

IN-SPACE EXPERIMENTS PLANNING

OAST — InSTEP

ASEB PANEL ON NASA'S R&T PROGRAM	JUNE,	1983
INDUSTRY / DOD WORKSHOP	FEB,	1984
ADMINISTRATOR'S POLICY STATEMENT	APRIL,	1984
ASEB PANEL ON IN-SPACE ENGINEERING AND TECHNOLOGY DEVELOPMENT	MAY,	1985
OAST IN-SPACE TECHNOLOGY WORKSHOP	OCT,	1985
INITIATION OF IN-REACH / OUT-REACH PROGRAMS	OCT,	1986
SSTAC AD HOC COMMITTEE ON THE USE OF SPACE STATION FOR IN-SPACE ENGINEERING R&T	AUG,	1987
SPACE STATION OPERATIONS TASK FORCE	OCT,	1987
NASA MANAGEMENT STUDY GROUP (NMSG - 24)	DEC,	1987
NASA CENTER SCIENCE ASSESSMENT TEAM	MAY,	1988

INSTEP 88-001

IN-SPACE TECHNOLOGY EXPERIMENTS PROGRAM

OAST InSTEP

- NASA EXPERIMENTS
  - ARISE FROM THE R&T BASE OR FOCUSED PROGRAMS
  - INCLUDE PRESENTLY ONGOING EXPERIMENTS
- INDUSTRY/UNIVERSITY EXPERIMENTS
  - FOLLOWING THROUGH ON OUR COMMITMENTS IN THE OUT-REACH PROGRAM
- INTERNATIONAL EXPERIMENTS
  - COOPERATIVE ACTIVITIES WITH OUR ALLIES

INSTEP 88-010

NASA IN-SPACE TECHNOLOGY EXPERIMENTS

- EXPERIMENTS CONTINUALLY ARISING AS A NATURAL EXTENSION OF R&T BASE AND FOCUSED PROGRAMS CONDUCTED BY NASA, SUCH AS

  - ORBITER EXPERIMENTS PROGRAM (OEX)
  - LONG DURATION EXPOSURE FACILITY (LDEF)
  - LiDAR IN-SPACE TECHNOLOGY EXPERIMENT (LITE)
  - ARCJET AUXILIARY PROPULSION SYSTEM
  - SPACE STATION STRUCTURAL CHARACTERIZATION
  - AEROBRAKING
  - ETC

INDUSTRY/UNIVERSITY IN-SPACE EXPERIMENTS

OAST InSTEP

- PROVIDE ACCESS TO SPACE FOR INDUSTRY AND UNIVERSITIES TO DEVELOP SPACE TECHNOLOGY

  - ENTHUSIASTIC RESPONSE OF AEROSPACE COMMUNITY TO OUT-REACH SOLICITATION

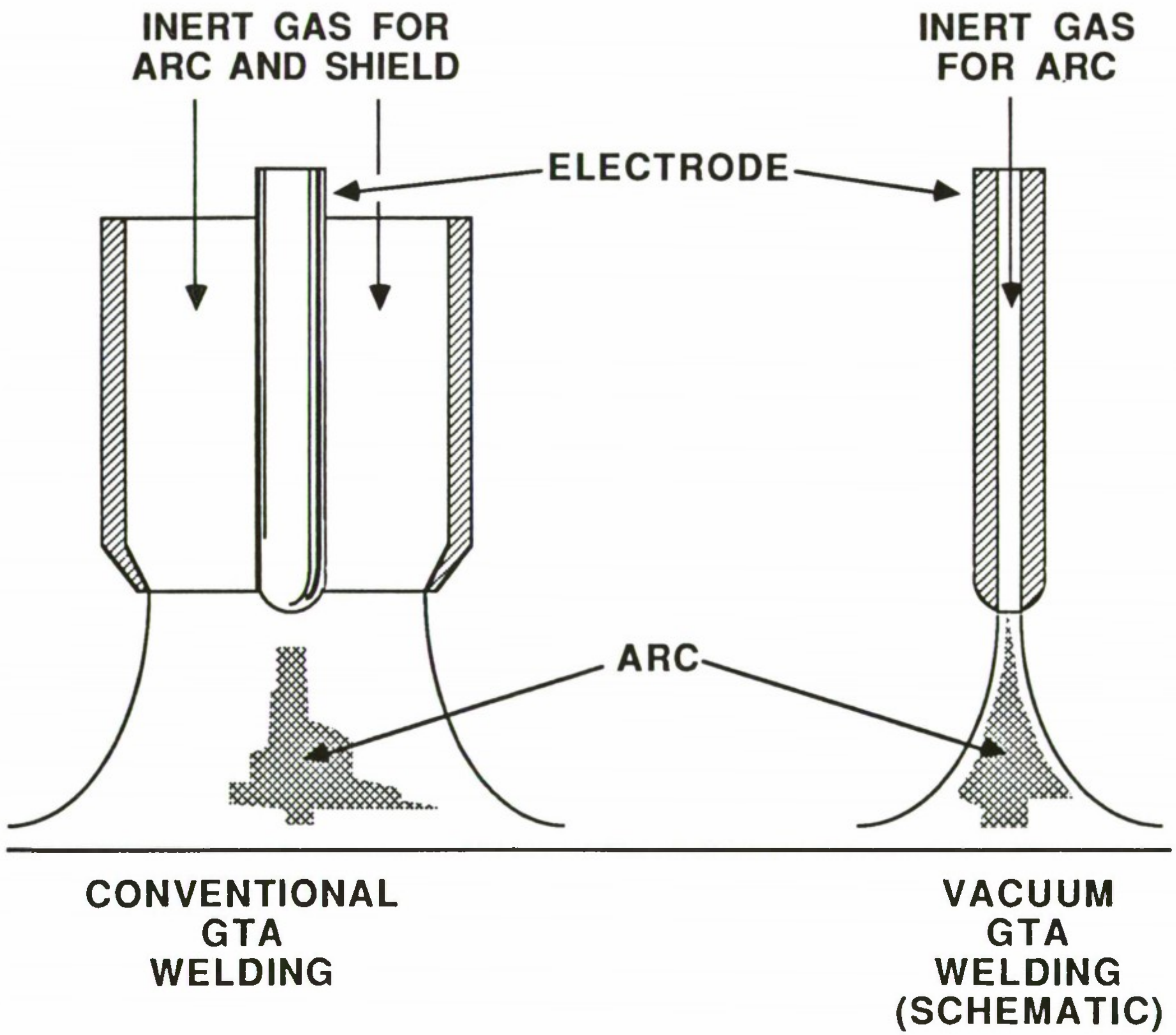
- OAST HAS COMMITTED TO AEROSPACE COMMUNITY TO SERVE AS CONDUIT FOR TECHNOLOGY DEVELOPMENT IN SPACE

  - PERIODIC RESOLICITATIONS TO INDUSTRY/UNIVERSITY COMMUNITY FOR EXPERIMENT DEFINITION, DEVELOPMENT, AND FLIGHT

INSTEP 88-004

IN-SPACE PLASMA ARC WELDING

O-A-S-T



88-1372

INTERNATIONAL IN-SPACE EXPERIMENTS

OAST InSTEP

- PROMOTES COOPERATION WITH ALLIES
- LEVERAGES TECHNOLOGY DEVELOPMENT BY OTHERS IN KEY AREAS
- LEVERAGES AND HUSBANDS SCARCE FLIGHT OPPORTUNITIES

IINSTEP 88-005

IN-SPACE EXPERIMENTS INITIATIVE - PHASE I

OAST InSTEP

- FLIGHT OPPORTUNITY RESTORED

- INITIATE MORE VIGOROUS PROGRAM ON SHUTTLE AND ELVs

  - OBTAIN DATA THAT CAN NOT BE OBTAINED ON THE GROUND

  - VALIDATE ADVANCED TECHNOLOGIES FOR EARLY USE IN FLIGHT PROJECTS

- GET A RUNNING START ON SPACE STATION

  - GEAR UP NASA, INDUSTRY, UNIVERSITY ACTIVITY

  - CONDUCT SPACE STATION PRECURSOR EXPERIMENTS

INSTEP 88-027

IN-SPACE EXPERIMENTS INITIATIVE - PHASE II

OAST InSTEP

- ROUTINE OPERATIONS IN LOW EARTH ORBIT WILL INITIATE ERA OF BOLD NEW INITIATIVES
  - NEED FOR TECHNOLOGY DEMONSTRATIONS FOR ENABLING TECHNOLOGIES WILL INCREASE
  - THE RANGE OF TECHNOLOGIES TO BE DEMONSTRATED IN SPACE WILL INCREASE
  - SPACE STATION WILL PROVIDE THE FACILITY FOR SIMPLER, FASTER ACCESS TO SPACE
  - SPACE STATION WILL ENABLE EXPERIMENTS NEEDING LONG-TERM HUMAN INTERACTION

- EXPERIMENTS PLANNED AND DEFINED FOR SPACE STATION DURING PHASE I WILL ENTER HARDWARE DEVELOPMENT STAGE

INSTEP 88-025

SUMMARY

OAST — InSTEP

- TECHNICAL NEED IDENTIFIED — 1983
- PLANNING COMPLETE — 1983-86
- COMMITMENTS MADE — 1986-88
  - INDUSTRY / UNIVERSITIES (VIA OUT-REACH)
  - CENTERS (VIA IN-REACH)
  - INTERNATIONAL COMMUNITY
- OPPORTUNITY FOR SPACE FLIGHT RESTORED
  - SHUTTLE, ELV MANIFESTING
  - SPACE STATION PLANNING

INSTEP 88-023

Office of
Aeronautics and
Space
Technology

UNIVERSITY PROGRAM

Presentation to

AIAA/OAST Conference on Space Technology

Steven C. Hartman
Program Manager
September 12, 1988

SPACE R&T STRATEGY

OAST

REVITALIZE TECHNOLOGY FOR LOW EARTH ORBIT APPLICATIONS

DEVELOP TECHNOLOGY FOR EXPLORATION OF THE SOLAR SYSTEM

MAINTAIN FUNDAMENTAL R&T BASE

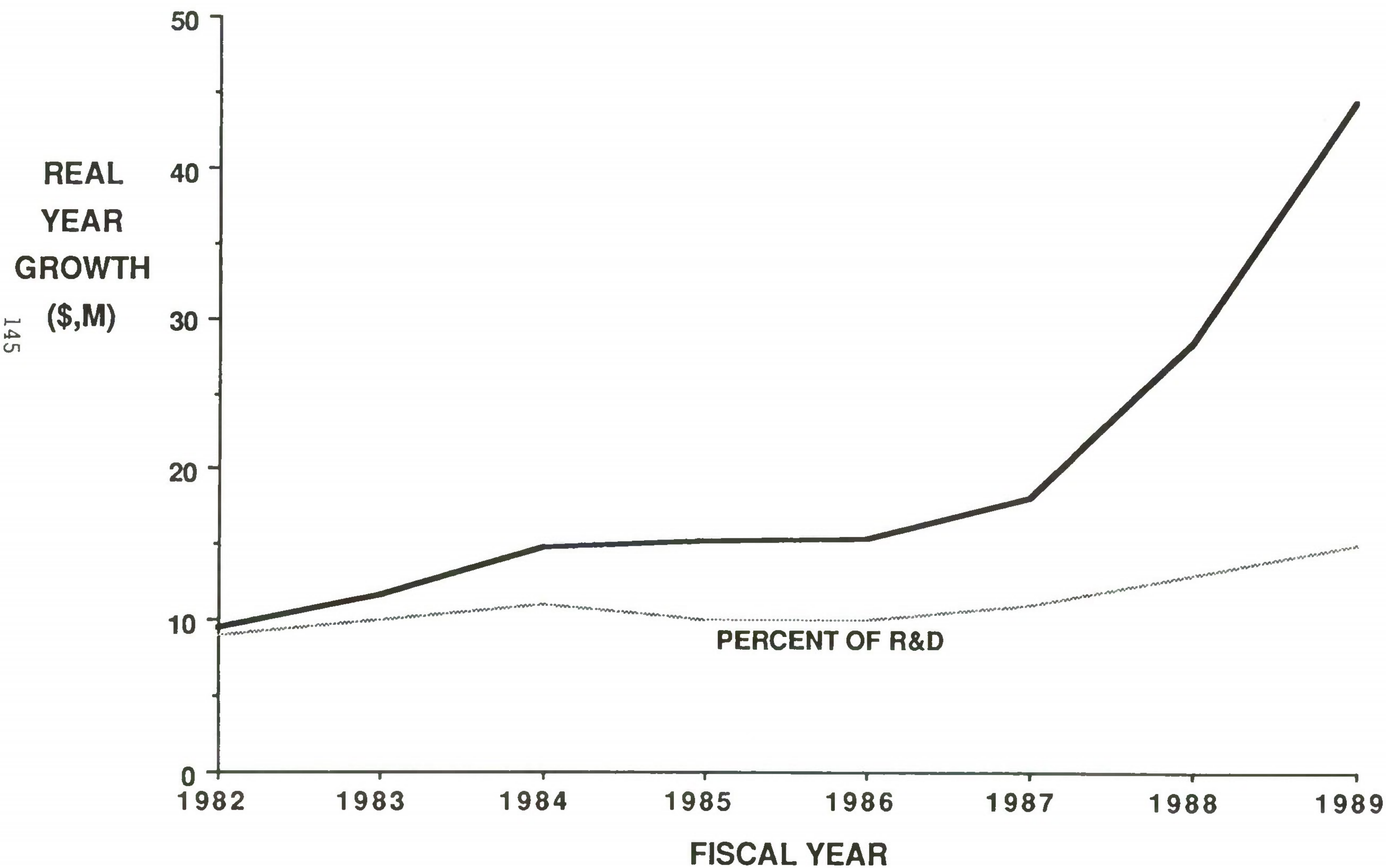
BROADEN PARTICIPATION OF UNIVERSITIES

EXTEND TECHNOLOGY DEVELOPMENT TO IN-SPACE EXPERIMENTATION

FACILITATE TECHNOLOGY TRANSFER TO USERS

OAST UNIVERSITY PROGRAM GROWTH
(SPACE)

OAST



88-2736

OAST UNIVERSITY PROGRAMS

OAST

BASIC RESEARCH GRANTS

RESEARCH INSTITUTES

JOINT UNIVERSITY INSTITUTES

CENTERS OF EXCELLENCE

AEROSPACE ADVANCED DESIGN PROGRAM

HYPERSONIC TRAINING AND RESEARCH PROGRAM

STATION UTILIZATION - TECHNOLOGY OUTREACH

GRADUATE PROGRAM IN AERONAUTICS

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

OAST UNIVERSITY PROGRAMS

OAST

BROADEN THE CAPABILITIES OF THE NATION'S ENGINEERING COMMUNITY TO PARTICIPATE MORE EFFECTIVELY IN THE U.S. CIVIL SPACE PROGRAM

OAST UNIVERSITY PROGRAMS

OAST

<u>WHAT WE ARE DOING DIFFERENTLY:</u>

MORE EFFICIENT USE OF ANNOUNCEMENTS OF OPPORTUNITY

INDEPENDENT OPPORTUNITIES TO CONTRIBUTE INNOVATIVELY

PEER REVIEW

LONG-TERM FUNDING

STRONGER INDUSTRY/UNIVERSITY PARTNERSHIPS WITH NASA

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM


Proposal for
University Space
Engineering
Research Program
Tech
University
TECH UNIVERSITY

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

OAST

GRANTS UP TO $1-2M PER YEAR FOR A MINIMUM OF 4 YEARS

FLEXIBLE SO UNIVERSITIES ARE FREE TO BE INNOVATIVE

CENTER CONCEPT FOR MULTI-DISCIPLINARY RESEARCH AND EDUCATION

COLLABORATIVE ACTIVITY INVOLVING NASA CENTERS AND INDUSTRY

FUNDING SUPPORT TO U.S. STUDENTS ONLY

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

OAST

<u>CRITERIA:</u>

STRENGTH OF EXISTING ENGINEERING PROGRAM

QUALITY OF THE PROPOSED SPACE RESEARCH

POTENTIAL IMPACT

MANAGEMENT AND COMPETENCE

GROWTH POTENTIAL

OAST

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

EVALUATION PROCESS

- PEER REVIEW
  - -- EACH PROPOSAL ASSIGNED 5 REVIEWERS
  - -- RESEARCHERS FROM NASA, INDUSTRY, UNIVERSITIES, OTHER GOVERNMENT AGENCIES
- STEERING COMMITTEE
  - -- STANDARDIZED REVIEW OF ALL PROPOSALS
  - -- WORKING GROUP INTERMEDIATE PROCESS
  - -- SITE VISITS
  - -- RECOMMEND SELECTIONS
- SELECTION OFFICIAL

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

OAST

NINE CENTERS SELECTED FOR FY 1988

- UNIVERSITY OF ARIZONA – CENTER FOR UTILIZATION OF LOCAL PLANETARY RESOURCES
- UNIVERSITY OF CINCINNATI – HEALTH MONITORING TECHNOLOGY CENTER FOR SPACE PROPULSION SYSTEMS
- UNIVERSITY OF COLORADO, BOULDER – CENTER FOR SPACE CONSTRUCTION
- UNIVERSITY OF IDAHO – VERY LARGE SCALE INTEGRATED HARDWARE ACCELERATION CENTER FOR SPACE RESEARCH
- MASSACHUSETTS INSTITUTE OF TECHNOLOGY – CENTER FOR SPACE ENGINEERING RESEARCH FOCUSED ON CONTROLLED STRUCTURES TECHNOLOGY
- UNIVERSITY OF MICHIGAN – CENTER FOR NEAR-MILLIMETER WAVE COMMUNICATION
- NORTH CAROLINA STATE AT RALEIGH & NORTH CAROLINA AGRICULTURAL AND TECHNICAL STATE UNIVERSITY – MARS MISSION RESEARCH CENTER
- PENNSYLVANIA STATE UNIVERSITY – CENTER FOR SPACE PROPULSION ENGINEERING
- RENSSELAER POLYTECHNIC INSTITUTE – INTELLIGENT ROBOTIC SYSTEMS FOR SPACE EXPLORATION

UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

OAST

<u>COLLABORATIVE ACTIVITIES:</u>

EXCHANGE OF PERSONNEL

FACILITY USE

STUDENT RESEARCH

ADVISORY SERVICES

TECHNICAL EXCHANGES

ETC.

Office of
Aeronautics and
Space
Technology

PROPULSION, POWER & ENERGY

Presentation to

AIAA/OAST Conference on Space Technology

Gregory M. Reck
Director, Propulsion
Power, & Energy Division
September 13, 1988

PROPULSION, POWER & ENERGY DIVISION

OAST

OVERVIEW	*G. RECK*
SPACE PROPULSION	*L. DIEHL*
LAUNCH VEHICLE PROPULSION	*R. RICHMOND*
POWER	*R. J. SOVIE*
LIFE SUPPORT SYSTEMS	*J. LAWLESS*

PROPULSION, POWER & ENERGY DIVISION

OAST

PROGRAM ELEMENTS

PROPULSION

R & T BASE

CSTI

EARTH TO ORBIT
BOOSTER

PATHFINDER

CHEMICAL TRANSFER
CARGO VEHICLE
CRYOGENIC DEPOT

POWER

R & T BASE

CSTI

HIGH CAPACITY

PATHFINDER

SURFACE
SP-100
ROVER

LIFE SUPPORT SYSTEMS

R & T BASE

PATHFINDER

PHYS/CHEM LIFE SUPPORT
EVA/SUIT

PROPULSION, POWER & ENERGY DIVISION

OAST

RESEARCH & TECHNOLOGY BASE PROGRAM

	HQ MANAGER
PROPULSION	
SPACE TRANSPORTATION	*R. ZURAWSKI*
LOW THRUST PRIMARY & AUXILIARY	*G. BENNETT*
LUNAR/PLANETARY	*R. ZURAWSKI*
ADVANCED CONCEPTS	*G. BENNETT*
POWER	
PHOTOVOLTAIC ENERGY CONVERSION	*G. BENNETT*
CHEMICAL ENERGY CONVERSION	*G. BENNETT*
THERMAL ENERGY CONVERSION	*A. D. SCHNYER*
POWER MANAGEMENT	*G. BENNETT*
THERMAL MANAGEMENT	*M. LOPEZ-TELLADO*
LIFE SUPPORT SYSTEMS	*P. EVANICH*

PROPULSION, POWER & ENERGY DIVISION

OAST

	HQ MANAGER	CENTER FOCUS
CSTI ELEMENTS		
EARTH-TO-ORBIT PROPULSION	F. STEPHENSON	MARSHALL
BOOSTER PROPULSION	F. STEPHENSON	MARSHALL
HIGH CAPACITY POWER	A. D. SCHNYER	LEWIS
PATHFINDER ELEMENTS		
CHEMICAL TRANSFER PROPULSION	R. ZURAWSKI	LEWIS
CARGO VEHICLE TRANSFER PROPULSION	G. BENNETT	LEWIS
CRYOGENIC FLUID DEPOT	M. LOPEZ-TELLADO	LEWIS
SP-100	A. D. SCHNYER	JPL
SURFACE POWER	M. LOPEZ-TELLADO	LEWIS
*ROVER (POWER)	G. BENNETT	JPL
PHYS/CHEM LIFE SUPPORT SYSTEMS	P. EVANICH	AMES
*EVA/SUIT (PORTABLE LIFE SUPPORT)	P. EVANICH	AMES

* Portions of other Pathfinder elements

SPACE PROPULSION TECHNOLOGY AND CRYOGENIC FLUID DEPOT

DR. LARRY A. DIEHL

NASA LEWIS RESEARCH CENTER

September 12-13, 1988

SPACE PROPULSION PROGRAM AREAS

BASE R & T

PATHFINDER

ON-BOARD

CHEMICAL TRANSFER

LUNAR

CARGO VEHICLE

ADVANCED CONCEPTS

ORBIT TRANSFER

MAJOR THRUSTS

CHEMICAL PROPULSION
- LOX/LH_2
- EXPANDER CYCLE

ELECTRIC PROPULSION
- MPD
- ION

CHEMICAL TRANSFER PROPULSION

PROGRAM OBJECTIVES

- PROVIDE VALIDATED TECHNOLOGY BASE FOR HIGH PERFORMANCE, SPACE BASED, THROTTLEABLE, LOX/HYDROGREN EXPANDER CYCLE ENGINES
  - VALIDATION AT COMPONENT AND ENGINE SYSTEMS LEVEL
  - RESPONSIVE TO CONCURRENT MISSION STUDIES
- ENABLE SIGNIFICANT REDUCTIONS IN ON-ORBIT PROPELLANT MASS REQUIRED FOR LUNAR/PLANETARY TRANSFER AND DESCENT/ASCENT VEHICLE OPERATIONS

TECHNOLOGY ISSUES

- HIGH PRESSURE ENGINE OPERATION (PERFORMANCE)
- DEEP THROTTLING WITH MINIMUM PERFORMANCE LOSS
- LONG-LIFE, HIGH RELIABILITY DESIGN CAPABILITY
- DESIGN FOR ON-ORBIT MAINTAINABILITY
- AUTOMATED FLIGHT READINESS OPERATIONS
- FAULT-TOLERANT ENGINE OPERATIONS METHODOLOGY

CHEMICAL TRANSFER PROPULSION

PROGRAM DESCRIPTION

- Responsible Centers: LeRC (N. Hannum) & MSFC (S. McIntyre)

MILESTONES

• COMPONENT TECHNOLOGY VERIFICATION	FY 1992
• TESTBED SYSTEM PERFORMANCE VALIDATION	FY 1994
• AUTOMATED INSPECTION/CHECKOUT TECHNIQUES DEMONSTRATED	FY 1996
• HEALTH MONITORING/CONTROL SYSTEM DEFINED	FY 1997
• FAULT TOLERANT ENGINE OPS DEMONSTRATED	FY 1999

AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

NASA
Lewis Research Center

CHEMICAL TRANSFER PROPULSION

DELIVERABLES

• **COMPUTER CODES**	FOR SIMULATING INTERNAL ENGINE PROCESSES, DEFINING LOADS, PREDICTING PERFORMANCE, LIFE AND ENGINE TRANSIENT AND STEADY STATE OPERATIONS
• **ADVANCE DESIGN CONCEPTS**	FOR EXTENDING COMPONENT LIFE, ENHANCING PERFORMANCE, OPERATIONS AND CONTROLS
• **DIAGNOSTICS**	FOR COMPONENT CONDITION MONITORING AND INCIPIENT FAILURE DETECTION AND CORRECTIONS
• **EXPERIMENTAL DATA BASE**	FOR VALIDATION OF ADVANCED DESIGN CONCEPTS AND COMPUTER CODES
• **OPERATING ENGINE SYSTEM**	FOR DEVELOPMENT PROGRAM PROBLEM SOLVING AND PRODUCT IMPROVEMENTS

AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

CARGO VEHICLE PROPULSION

PROGRAM OBJECTIVES

- ESTABLISH FEASIBILITY OF ELECTRIC PROPULSION WITH

  Isp > 4000 sec
  EFFICIENCY > 0.60
  SPECIFIC MASS < 10 kg/kw
  SCALABLE TO MULTI-MEGAWATT

- DURABILITY FOR TOTAL IMPULSE OVER 10^8 N-sec PER ENGINE

TECHNOLOGY ISSUES

- SCALE-UP OF ION OPTICS TO HIGH POWER
- MPD EFFICIENCY AND LIFE FOR BOTH APPLIED FIELD AND SELF FIELD
- LIFE EVALUATION METHODS

AEROSPACE TECHNOLOGY DIRECTORATE

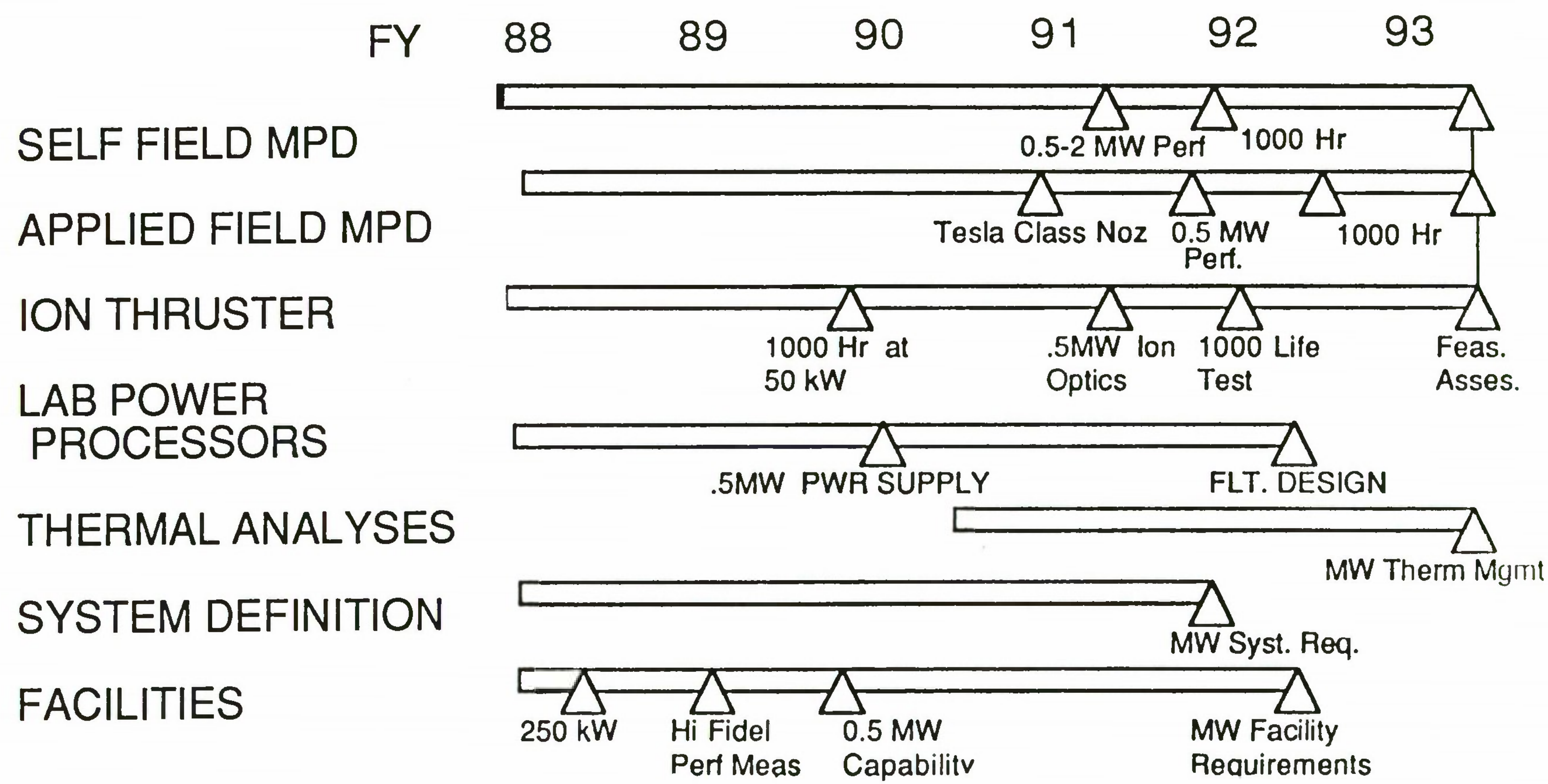
SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

CARGO VEHICLE PROPULSION

PROGRAM DESCRIPTION

- Responsible Centers: LeRC (D.Byers) & JPL (J.Stocky)



CARGO VEHICLE PROPULSION

DELIVERABLES

- BY 1993 PROVIDE:

  0.5 MW PERFORMANCE AND LIFE EVALUATION

  - SELF FIELD MPD
  - INDUCED FIELD MPD
  - ION THRUSTER

  MEGAWATT SYSTEM REQUIREMENT AND CONCEPT DEFINITION

  0.5 MW (STEADY STATE) FACILITY AND EVALUATION OF FACILITY IMPACTS

  CONCEPT SELECTION FOR PHASE II FOCUSED PROGRAM

- FOCUSED TECHNOLOGY PROGRAM (1994-98)
- FLIGHT VALIDATION PROGRAM (1998 →)

AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

ON-BOARD PROPULSION

PROGRAM DESCRIPTION

- Responsible Center: Lewis Research Center (D. Byers)

TASK	FY'88	FY'89	FY'90	FY'91	FY'92
Low Thrust Chemical	2600K 5LB Rocket	Integral H/O	Hot Rocket Scaling Tech.	Integrated H/O Rocket Demo	
Electric	1000 Hour, 500 Cycle Arcjet	10K Hour 5KW Ion Feas.	KW Arcjet Interface Evaluation	10 KW Ion Eng. Model System	*1KW Arcjet Flight Test
Fundamentals	Arcjet Plume Definition	2D Chamber Code Demo	Rocket Heat Transfer Model	DSMC Plume Code Verif.	Unified Rocket Code Verif.

* Separate Program. Not Approved.

AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

LUNAR/PLANETARY PROPULSION TECHNOLOGY

MAJOR THRUSTS

PROPULSION/TRAJECTORY STUDIES

- INJECTION PROPULSION
- ASCENT/DESCENT PROPULSION
- MIXED MODE

COMBUSTION STUDIES OF PROPELLANT OPTIONS

- GELLED METALLIC MONOPROPELLANTS
- LIQUIFIED ATMOSPHERES
- LIQUID BI-PROPELLANTS

LUNAR/PLANETARY PROPULSION TECHNOLOGY

- THRUST CHAMBER & SYSTEM TECH.
- PROPELLANT GELLING
- THRUST CHAMBER COOLING
- PROPELLANT FEED SYSTEMS

PROPELLANT PRODUCTION STUDIES

- O_2/CO SEPARATION/PRODUCTION
- LUNAR O_2 PRODUCTION
- LUNAR ALUMINUM PRODUCTION

AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

LUNAR/PLANETARY PROPULSION TECHNOLOGY

PROGRAM DESCRIPTION

- Responsible Centers:

Propulsion	LeRC	Carl A. Aukerman
Propellant Production	JPL	Jack Stocky

	FY'89	FY'90	FY'91	FY'92	FY'93
Milestones	O_2/CO Combustion		Gelled Metallized Combustion	Liquid Bi-Prop	O_2/CO Separation

AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

ADVANCED CONCEPTS

OBJECTIVE

- Theoretical & Experimental Research on Breakthru Propulsion

MAJOR THRUSTS

- Nuclear Fission/Fusion
- Advanced Electric
- Antimatter & Energetic Propellants
- Concept/Mission Analyses

PROGRAM DESCRIPTION

- Responsible Centers: LeRC (D.Byers) & JPL (J.Stocky)

TASK	FY'88	FY'89	FY'90	FY'91	FY'92
Nuclear Fission/Fusion		Nuc. Prop. Assessments		Mag. Nozzle Definition	
Advanced Electric	KW μWave Rocket	RF Thruster Demo	5T Magnetic Nozzle		Electrodeless Rocket Feas.
Antimatter/Energetic Props.		Anti. Mat ICF Def.	Prop. Study Complete		Anti. Mat. Sys. Eval.
Concept/Mission Analyses		Fusion Mission Eval.			

FLUID MANAGEMENT TECHNOLOGY

OBJECTIVE

TO DEVELOP AND VALIDATE THE TECHNOLOGY REQUIRED TO PERFORM STORAGE, SUPPLY, AND TRANSFER OF SUBCRITICAL CRYOGENIC LIQUIDS IN A MICROGRAVITY SPACE ENVIRONMENT

TECHNOLOGY AREAS

- LIQUID STORAGE
- LIQUID SUPPLY
- LIQUID TRANSFER
- FLUID HANDLING
- ADVANCED INSTRUMENTATION
- TANK MATERIALS AND STRUCTURES

PROJECT PATHFINDER
CRYOGENIC FLUID DEPOT

NASA
Lewis Research Center

OAST

PROGRAM OBJECTIVES

DEVELOPMENT OF DEPOT CONCEPTUAL DESIGNS

PERFORMANCE OF CRITICAL RESEARCH AND ADVANCEMENT OF TECHNOLOGY READINESS LEVELS IN THE AREAS OF:

- FLUID MANAGEMENT
- DEPOT OPERATIONS
- MATERIALS AND STRUCTURES
- ORBITAL OPERATIONS AND LOGISTICS
- SAFETY

DEFINITION OF IN-SPACE EXPERIMENT REQUIREMENTS

CENTER FOCUS

LEWIS RESEARCH CENTER (P. SYMONS)

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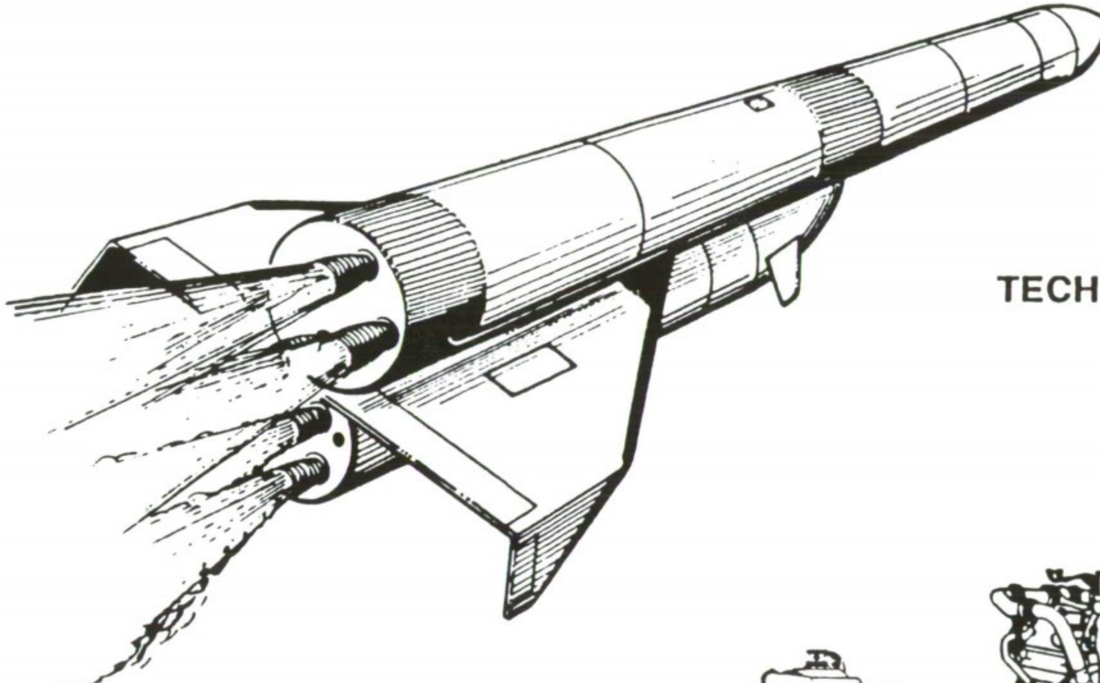
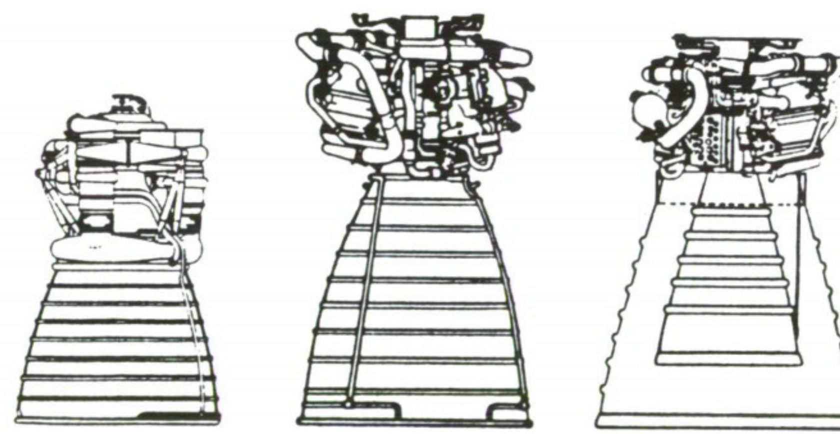
NASA
EARTH-TO-ORBIT PROPULSION R&T



TECHNOLOGY FOR FUTURE NASA MISSIONS



R.J. Richmond
NASA/MSFC
Sept. 13, 1988

EARTH-TO-ORBIT PROPULSION

PURPOSE:

- o PROVIDE A VALIDATED TECHNOLOGY BASE TO SUPPORT A RANGE OF PROPULSION SYSTEM OPTIONS FOR MINIMUM LIFE CYCLE COST FUTURE SPACE TRANSPORTATION SYSTEMS
- o MAINTAIN AND ENHANCE U.S. LEADERSHIP IN SPACE TRANSPORTATION

IMPLEMENTATION:

- o EARTH-TO-ORBIT PROPULSION R&T IS COMPOSED OF THREE PROGRAM ELEMENTS

R &T BASE PROGRAM

- Fundamental Processes
- New Concepts
- Far Term

CSTI

o EARTH-TO-ORBIT PROPULSION
- Oxygen/Hydrogen
- Oxygen/Hydrocarbon

o BOOSTER TECHNOLOGY
- Pressure-Fed Liquids
- Hybrids

EARTH-TO-ORBIT PROPULSION

BASE R&T PROGRAM

OBJECTIVE:

- EXPAND FUNDAMENTAL KNOWLEDGE AND UNDERSTANDING OF ROCKET ENGINE PROCESSES AND PRINCIPLES
- EXPLORE AND DEFINE ADVANCED TECHNOLOGIES APPLICABLE TO EARTH-TO-ORBIT PROPULSION

JUSTIFICATION:

- APPLICATION OF NEW CONCEPTS AND IMPROVED UNDERSTANDING OF THE FUNDAMENTALS HOLDS THE POTENTIAL FOR MAJOR ADVANCEMENTS IN ETO PROPULSION

SIGNIFICANCE:

- WILL ENABLE THE DEVELOPMENT OF FUTURE LAUNCH VEHICLES WITH FAR GREATER PAYLOAD DELIVERY CAPABILITY AT GREATLY REDUCED COST

EARTH-TO-ORBIT PROPULSION

BASE R&T PROGRAM

PROGRAM CONTENT:

- o FUNDAMENTALS OF COMBUSTION AND FLUID FLOW PROCESSES
- o VERY HIGH MIXTURE RATIO COMBUSTORS
- o METALLIZED GELLED PROPELLANTS
- o APPLICATIONS OF SUPERCONDUCTIVITY

EARTH-TO-ORBIT PROPULSION

CSTI EARTH-TO-ORBIT

OBJECTIVE:

- o PROVIDE AN EXPANDED VALIDATED TECHNOLOGY BASE FOR ADVANCED OXYGEN/HYDROGEN AND OXYGEN HYDROCARBON ETO PROPULSION SYSTEMS

JUSTIFICATION:

- o INCREASED BENEFITS TO SPACE TRANSPORTATION SYSTEMS THROUGH ADVANCEMENTS IN ETO PROPULSION SYSTEMS
  - PERFORMANCE
  - SERVICE LIFE
  - AUTOMATED OPERATIONS AND DIAGNOSTICS

SIGNIFICANCE:

- o WILL ENABLE A RANGE OF PROPULSION SYSTEM OPTIONS FOR MINIMIZING OVERALL SPACE TRANSPORTATION COSTS

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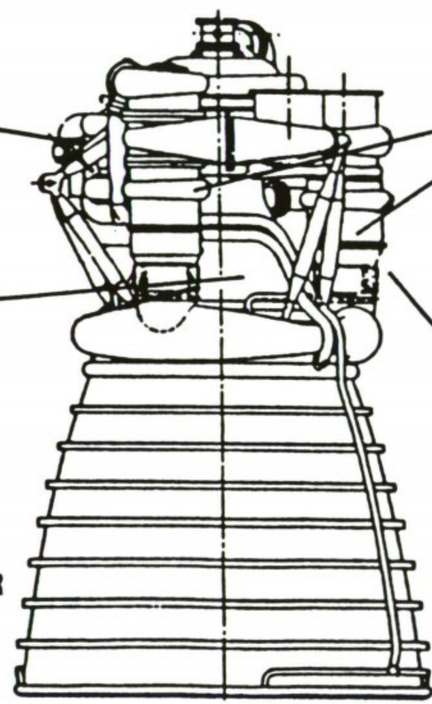
NASA CSTI EARTH-TO-ORBIT PROPULSION R&T PROGRAM

TECHNOLOGY THRUSTS



PREBURNER/GAS GEN

- UNIFORM TEMPERATURE TURBINE DRIVE GAS
- CARBON DEPOSITION

THRUST CHAMBER

- COMBUSTION EFFICIENCY
- COMBUSTION STABILITY
- PERFORMANCE PREDICTION
- CARBON DEPOSITION
- THERMAL BARRIER COATINGS
- FUEL COKING
- FUEL COOLANT/CHAMBER LINER COMPATIBILITY
- LOX COOLING
- COOLING PASSAGE GEOMETRY OPTIMIZATION
- TRANSLATING NOZZLE

TURBOMACHINERY

- BEARING DURABILITY
- ROTOR DYNAMICS
- AEROTHERMO LOADS
- COOLED TURBINES
- TURBINE BLADE DURABILITY
- HYDROGEN EMBRITTLEMENT
- TURBINE & PUMP SECTION EFFICIENCY

CONTROLS & SYSTEM MONITORING

- ADVANCED SENSORS
- DIAGNOSTIC TECHNIQUES
- CONTROL STRATEGY

CSTI EARTH-TO-ORBIT
Program Content

o ANALYTICAL/EMPIRICAL MODELS	PERFORMANCE AND LIFE PREDICTION - Flow Process Codes - Combustion Codes - Heat Transfer and Cooling - Loads Definition - Materials Behavior - Structural Response - Fatigue and Fracture
o ADVANCED COMPONENT TECHNOLOGY	METHODOLOGIES AND PROCESSES - Bearings - Seals - Turbine Blades - Active Dampers - Materials - Coatings - Manufacturing

CSTI EARTH-TO-ORBIT
Program Content (Cont'd)

o INSTRUMENTATION	SYSTEM MONITORING AND CONTROL - Performance Analysis - Engine Control - Safety Monitoring - Condition Monitoring
o ENGINEERING TESTING	SUBCOMPONENT VALIDATION - Models and Codes - Materials - Processes - Instruments
o SUBSYSTEM/TESTBED ENGINE TESTING	TRUE ROCKET OPERATING ENVIRONMENT VERIFCATION - Steady State - Transient - All Influences and Interactions Present

CSTI EARTH-TO-ORBIT
MAJOR DELIVERABLES

o VALIDATED ANALYTICAL CODES:

- Enhanced Structural Dynamics Codes for Internal Force Definition
- Enhanced Life Prediction Codes Based on Fracture, Fatigue
- Enhanced Rotordynamics Codes
- Enhanced Engine Performance Prediction/Combustion Codes

o ADVANCED DESIGN METHODOLOGY FOR:

- High Efficiency, Long Life Turbines, Pumps, Bearings, and Ducts
- Combustor Stability and Cooling
- Turbomachinery Stability
- Safety Monitoring, Condition Monitoring, and Control Systems

BOOSTER TECHNOLOGY

CSTI BOOSTER PROPUSLION

OBJECTIVE:

- o DEVELOP THE VALIDATED DATA BASE AND DESIGN METHODOLOGY FOR ADVANCED BOOSTER PROPULSION SYSTEMS

  - HIGH THRUST
  - OXYGEN/HYDROCARBON PRESSURE-FED LIQUIDS
  - OXYGEN/SOLID FUEL HYBRIDS

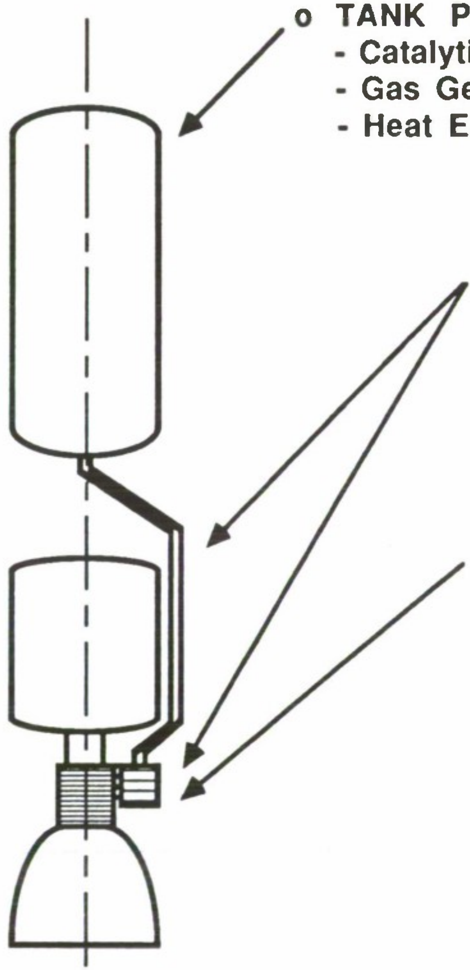
JUSTIFICATION:

- o PRESSURE-FED AND HYBRID PROPULSION HAVE INCREASED PERFORMANCE, THRUST TERMINATION, AND THRUST TAILORING CHARACTERISTICS

SIGNIFICANCE:

- o WILL ENABLE ALTERNATIVE OPTIONS TO THE SOLID ROCKET BOOSTERS FOR FUTURE SPACE SHUTTLE AND OTHER LAUNCH VEHICLE APPLICATIONS THAT OFFER SAFE-ABORT AND INCREASED PAYLOAD CAPABILITY

PRESSURE-FED LIQUIDS - TECHNOLOGY ISSUES

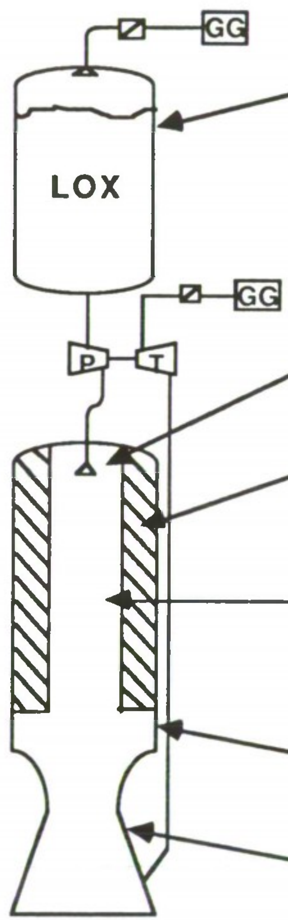


- o TANK PRESSURIZATION SYSTEMS
  - Catalytic
  - Gas Generator
  - Heat Exchanger
- o COMBUSTION PERFORMANCE & STABILITY
  - High Frequency "Acoustic" Stability
  - Low Frequency "Chugging" Modal Definition
  - Combustion Efficiency
- o THRUST CHAMBER
  - Cooling
  - Water Impact/Corrosion
  - Refurbishment

CSTI BOOSTER PROPULSION
PROGRAM CONTENT

- o PRESSURE-FED LIQUIDS
  - ANALYTICAL MODELS
    - Low Pressure, Large Scale Combustors
    - Tank Pressurization
  - LABORATORY, SMALL SCALE TESTING FOR CODE VALIDATION
  - LARGE SCALE COMPONENT TESTING FOR DESIGN METHODOLOGY VERIFICATION
- o HYBRIDS
  - ANALYTICAL MODELS
    - Combustion Processes
    - Propellant Feed System
  - LABORATORY, SMALL SCALE TESTING FOR CODE VALIDATION
  - SUBSCALE MOTOR TESTING FOR DESIGN METHODOLOGY VERIFICATION

HYBRIDS - TECHNOLOGY ISSUES



- o OXIDIZER FEED SYSTEM
  - Tank Pressurization Gas Generator
  - Turbomachinery
  - Turbine Drive Gas Generator
- o IGNITION SYSTEM OPTIMIZATION
- o FUEL GRAIN ASSESSMENT
  - Composition, Producibility
  - Burning Rate Characteristics
  - Mechanical Properties
- o INTERNAL BALLISTICS
  - Propellant Tailoring
  - Oxidizer Injection
  - Combustion Process Optimization
- o INSULATION MATERIALS CHARACTERIZATION
- o NOZZLE DESIGN AND FABRICATION

BOOSTER TECHNOLOGY

CSTI BOOSTER PROPULSION
MAJOR DELIVERABLES

o VALIDATED ANALYTICAL CODES:

- Low to Moderate Pressure, Bipropellant Combustion Processes
- Hybrid Combustion Processes
- High and Low Mixture Ratio Combustion for Tank Pressurization
- In-Tank Condensible Predictions

o ADVANCED DESIGN METHODOLOGY FOR:

- Pressure-Fed Combustor Design with High Performance, Stable Combustion, Minimum Pressure Drop Cooling, and Minimum Weight Ablative
- Hybrid Solid Fuel Grain Design, Oxidizer Injection and Ignition Systems
- High and Low Mixture Ratio Combustors
- High and Low Mixture Ratio Ignition Systems

SPACE POWER TECHNOLOGIES

BY

RONALD J. SOVIE
DEPUTY CHIEF, POWER TECHNOLOGY DIVISION

NASA LeRC

AIAA/OAST CONFERENCE ON
CSTI AND PATHFINDER
9/13/88

RJS.9-13.001

WHAT WILL BE DISCUSSED

- OAST BASE RESEARCH AND TECHNOLOGY POWER PROGRAM
- PATHFINDER
  - ROVER POWER
  - SURFACE POWER
  - SPACE NUCLEAR POWER (SP-100)
- CSTI
  - HIGH CAPACITY POWER

RJS.9-13.002

OAST

BASE R & T

POWER PROGRAM

RJS.9-13.008

SPACE ENERGY CONVERSION R&T BASE
PROJECT ELEMENTS

- **PHOTOVOLTAICS** — LeRC, JPL
  - CELLS, BLANKETS, MODULES — D. FLOOD P. STELLA
- **ELECTROCHEMISTRY** — LeRC, JPL
  - BATTERIES, FUEL CELLS — L. THALLER G. HALPRIN
- **THERMAL ENERGY CONVERSION** — LeRC, JPL
  - ADVANCED SOLAR DYNAMICS, AMTEC — M. WARSHAY P. BANKSTON
- **POWER MANAGEMENT** — LeRC, JPL
  - FAULT TOLERANT, 20 kHz, SPACE ENVIRON. ELECTROPHYSICS — R. BERCAW J. KLEIN
- **THERMAL MANAGEMENT** — LeRC, GSFC, JSC
  - ADVANCED RADIATORS, LOW TEMP. HEAT PUMPS, 0-G — M. WARSHAY T. SWANSON W. ELLIS

RJS.9-13.006

OAST

PATHFINDER POWER SYSTEMS - MISSIONS

- **ROVER POWER**
  - LUNAR/MARS EXPLORATION
  - ROBOTIC EXPLORATION AND SAMPLE RETURN
  - LUNAR/MARS BASES
- **SURFACE POWER**
  - LUNAR/MARS OUTPOSTS
  - PILOTED MARS EXPEDITION
  - SPACECRAFT POWER
    - **EARTH ORBIT**
    - **OBSERVERS**
    - **TRANSFER**
    - **OTHERS**
- **SPACE NUCLEAR POWER (SP-100)**
  - LUNAR/MARS BASES
  - MANNED MARS EXPEDITION
  - ADVANCED EARTH ORBIT OPERATIONS
  - OUTER PLANETARY EXPLORATION

RJS.9-13.015

NASA
C-87-11751

SP-100

ROLE OF NUCLEAR POWER IN SPACE

LUNAR BASE

BASE CENTRAL UTILITY POWER
NUCLEAR SPACE TRANSPORT (NST)
COMMUNICATIONS SATELLITE POWER

MANNED MARS MISSION

BASE CENTRAL UTILITY POWER
NST CARGO VEHICLE
MANNED VEHICLE APU
COMMUNICATIONS SATELLITE POWER

PLANET EARTH

CO-ORBITING PLATFORM UTILITY POWER

PLANETARY EXPLORATION

NST CARGO/EXPLORATION VEHICLE

CD-87-28550

OAST

EVOLUTIONARY POWER REQUIREMENTS FOR SURFACE BASE OPERATIONS

UNMANNED PRECURSOR	MANNED OUTPOST/CAMP	INTERIM BASE	SUSTAINED BASE
2 kWe	~ 25-100 kWe	500 kWe	2000 kWe
• ORBITER	• HABITAT (6 CREW)	• HABITAT (15 CREW)	• HABITAT (24 CREW)
• ROVER	• LABORATORY	• ADD'L LABS	• RESEARCH FACILITIES
• SAMPLE RETURN	• SCIENCE EXPTS	• EXTENDED SCIENCE	• SUSTAINED SCIENCE
• FARSIDE COMSAT	• LOX PILOT PLANT	• IN-SITU RESOURCES PLANT	• INCREASED LOX PRODUCTION
	• SITE PREP	• CELSS RESEARCH	• METALS PRODUCTION
	• ROVERS/TRAILERS	• SURFACE SURVEYS	• MANUFACTURING
	• LANDER/ASCENT VEHICLE	• MINING	• CERAMICS PRODUCTION
		• LOX PRODUCTION	• FOOD PRODUCTION
		• MATL'S PILOT PLANT	• PRODUCT EXPORT
		• REUSABLE LEM CARGO VEHICLE	• MASS DRIVER

RJS.9-13.027

OAST

LUNAR POWER SYSTEM MASS AND MARS BASES

100 kWe

	SOA SOLAR	ADV SOLAR	NUCLEAR 4Π	NUCLEAR SURFACE
LUNAR	3,300,000	33,000	11,900	4000
MARS	120,000	12,500	11,900	4000

500 kWe

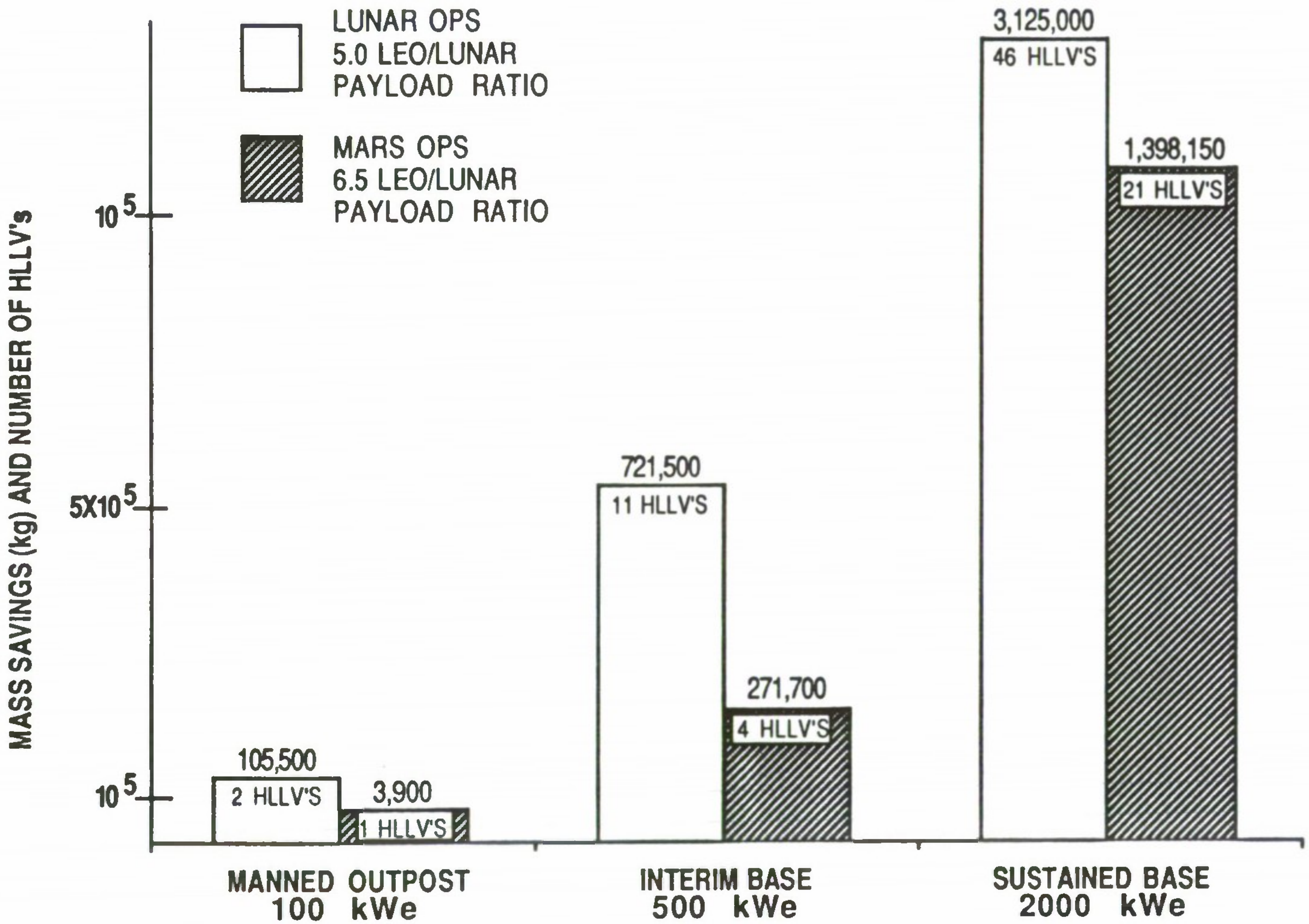
	SOA SOLAR	ADV SOLAR	NUCLEAR 4Π	NUCLEAR SURFACE
LUNAR	—	165,000	20,700	12,000
MARS	—	62,500	20,700	12,000

RJS.9-13.030

OAST

MASS SAVINGS IN LEO FOR LUNAR AND MARS OPERATIONS

NUCLEAR (4 PI SHIELD TRANSPORTED FROM EARTH)
VERSUS ADVANCED SOLAR



RJS.9-13.031

OAST

MARS/LUNAR BASE POWER SYSTEM PHILOSOPHY

- SPACECRAFT, INITIAL CAMP BASED ON ADVANCED SOLAR POWER SYSTEMS (10 - 25 kWe MODULES)

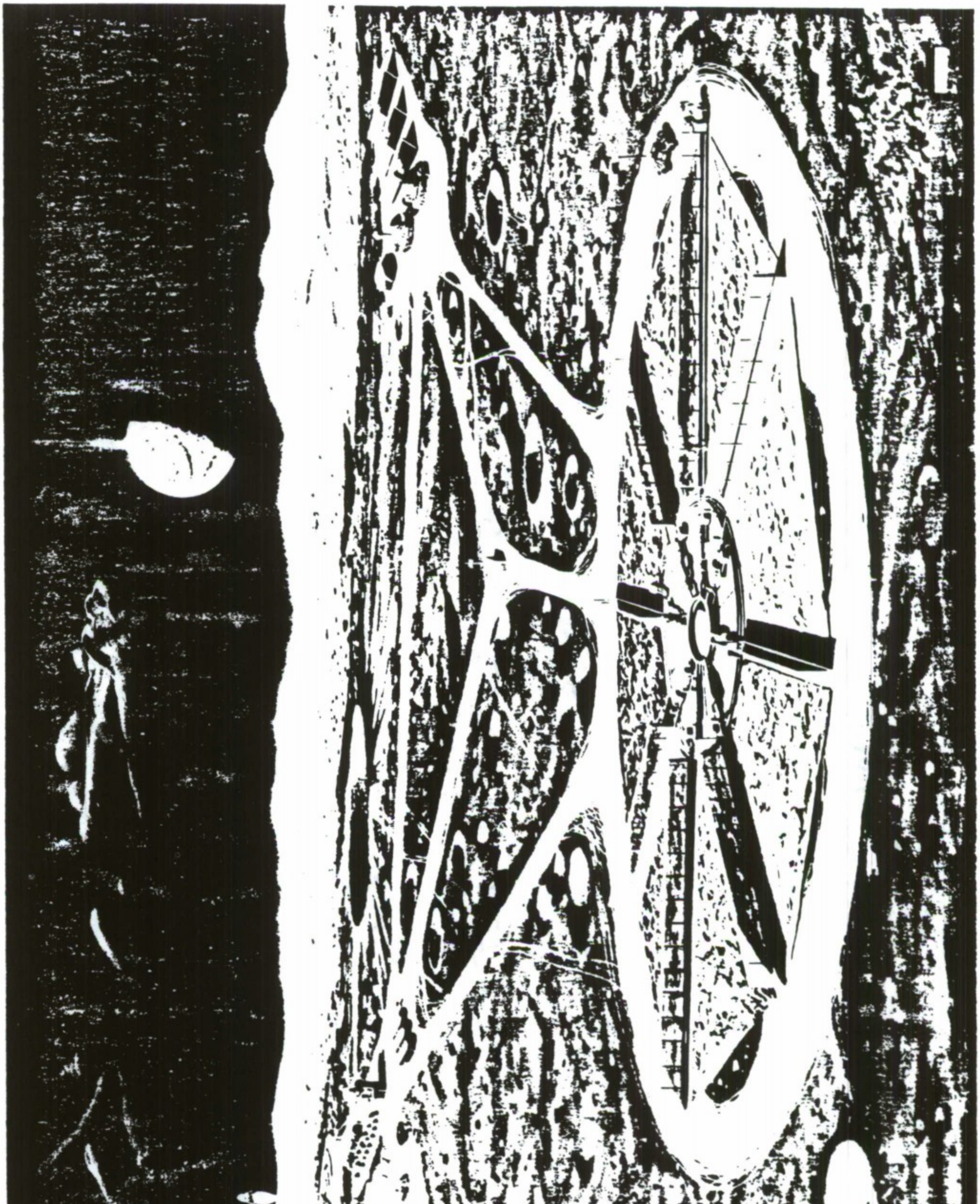
- SURFACE PREPARATION FOR NUCLEAR POWER

- EVOLUTION TO NUCLEAR POWER PROVIDES HUNDREDS TO THOUSANDS OF kWe

- PATHFINDER - SOLAR POWER
  - SP-100 GES SUPPORT

- CSTI - HIGH CAPACITY POWER (NUCLEAR)

RJS.9-13.014



NASA
C-88-86964

OAST

TECHNOLOGY GOALS

- EARTH ORBITAL, SPACECRAFT, OTHER APPLICATIONS

SOA		
SOLAR 3-6 W/kg	⟹	16-20 W/kg
NUCLEAR	⟹	15-40 W/kg

RJS.9-13.032

OAST

PATHFINDER

RJS.9-13.009

SURFACE POWER SYSTEMS

GOAL: DEMONSTRATE FEASIBILITY OF CRITICAL COMPONENT TECHNOLOGIES NECESSARY FOR INITIAL LUNAR/MARS CAMPS, SPACECRAFT POWER SYSTEMS

REQUIREMENTS:	~ 3 We/kg - LUNAR CAMP	14 DAYS	D/N CYCLE
	~ 8 We/kg - MARS CAMP	12 HR	D/N CYCLE

ENERGY CONVERSION 40 $\longrightarrow$ 300 W/kg

ENERGY STORAGE 40 $\longrightarrow$ 500-1000 Whr/kg

- MISSION DEPENDENT

POTENTIAL FOR SUCCESSFUL OPERATION ON MARS, LUNAR SURFACES

RJS.9-13.020

OAST

SURFACE POWER SYSTEMS
PROJECT ELEMENTS

- **MISSIONS AND SYSTEMS ANALYSIS**
- **H_2 -O_2 REGENERATIVE FUEL CELL**
- **PHOTOVOLTAIC POWER**
  - AMORPHOUS SILICON CELLS/BLANKETS
  - ADVANCED ARRAY STRUCTURES
- **ADVANCED SOLAR DYNAMICS**
  - CONCEPTUAL DESIGN STUDY
- **POWER CONDITIONING/CONTROL**
- **ENVIRONMENTAL COMPATIBILITY**

RJS.9-13.021

OAST

SURFACE POWER SYSTEMS
MAJOR DELIVERABLES
FY'93

- DEMONSTRATE 2000 HR OPERATION ON 65% REGENERATIVE FUEL CELL
  - 300F, 200 PSI
  - HIGH PRESSURE ELECTROLYZER (3000 PSI)
  - BUILDING BLOCK STACK
- 1 kWe DEMONSTRATION AMORPHOUS SILICON ON KAPTON
  - 2000 W/kg
- CONCEPTUAL DESIGN REDUCED-G ARRAY STRUCTURE
  - .46 kg/m^2

300 W/kg

- CONCEPTUAL DESIGN OF SOLAR DYNAMIC LUNAR/MARS POWER SYSTEMS
  - ELECTRICAL, THERMAL 3 - 8 W/kg
- POWER CONDITIONING CONTROL DESIGN/ENVIRONMENTAL COMPATIBILITY

RJS.9-13.022

OAST

SURFACE POWER SYSTEMS

- **MAJOR LABORATORIES**
  - LeRC - LEAD CENTER
  - TECHNICAL SUPPORT FROM JPL, LANL
- **CONTACT - J. BOZEK, LeRC**

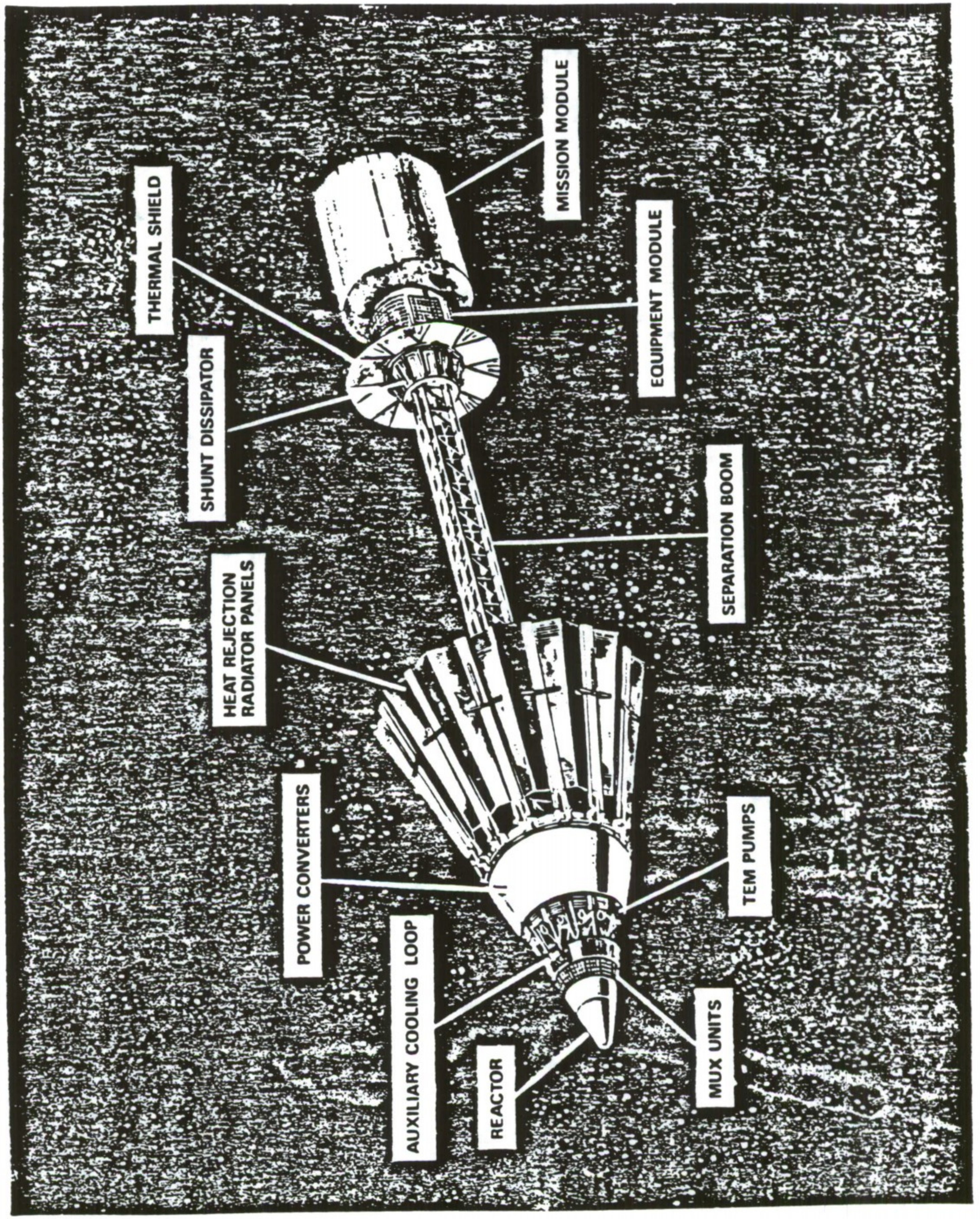
RJS.9-13.023

SPACE NUCLEAR POWER SP-100

- **PROVIDES NASA SUPPORT TO TRI-AGENCY, DOE/NASA/DOD, SP-100 GROUND ENGINEERING SYSTEM (GES) DEVELOPMENT PROGRAM**
  - ENSURES REACTOR AVAILABLE FOR NASA APPLICATIONS

- **REQUIREMENTS**
  - 100 kWe
  - 7 - 10 YEARS LIFE
  - > .95 RELIABILITY
  - 30 W/kg
  - 1/3 SHUTTLE BAY

RJS.9-13.024


THERMAL SHIELD
MISSION MODULE
SHUNT DISSIPATOR
EQUIPMENT MODULE
HEAT REJECTION RADIATOR PANELS
SEPARATION BOOM
POWER CONVERTERS
TEM PUMPS
AUXILIARY COOLING LOOP
REACTOR
MUX UNITS

OAST

SPACE NUCLEAR POWER SP-100
MAJOR DELIVERABLES

- 2.5 MW_T REACTOR TEST - FY'92
- SPACE SUBSYSTEM TEST - 15 kWe - FY'94

MAJOR LABORATORIES

DOE - PGM. DIR. - E. WAHLQUIST
JPL - PROJECT MGMT. - V. TRUSCELLO
LeRC - NASA GES SUPPORT - H. BLOOMFIELD

RJS.9-13.025

CSTI
HIGH CAPACITY
POWER

RJS.9-13.033

CSTI HIGH CAPACITY POWER

- PROVIDES FOR INCREASED POWER, RELIABILITY AND LIFETIME FOR NUCLEAR SPACE POWER SYSTEMS USING THE SP-100 REACTOR WITH EITHER DYNAMIC OR STATIC CONVERSION SYSTEMS.

RJS.9-13.011

CSTI

HIGH CAPACITY NUCLEAR POWER

- FOCUSED TECHNOLOGY DEVELOPMENT TO ENHANCE CAPABILITY OF SPACE POWER SYSTEMS USING GES REACTOR

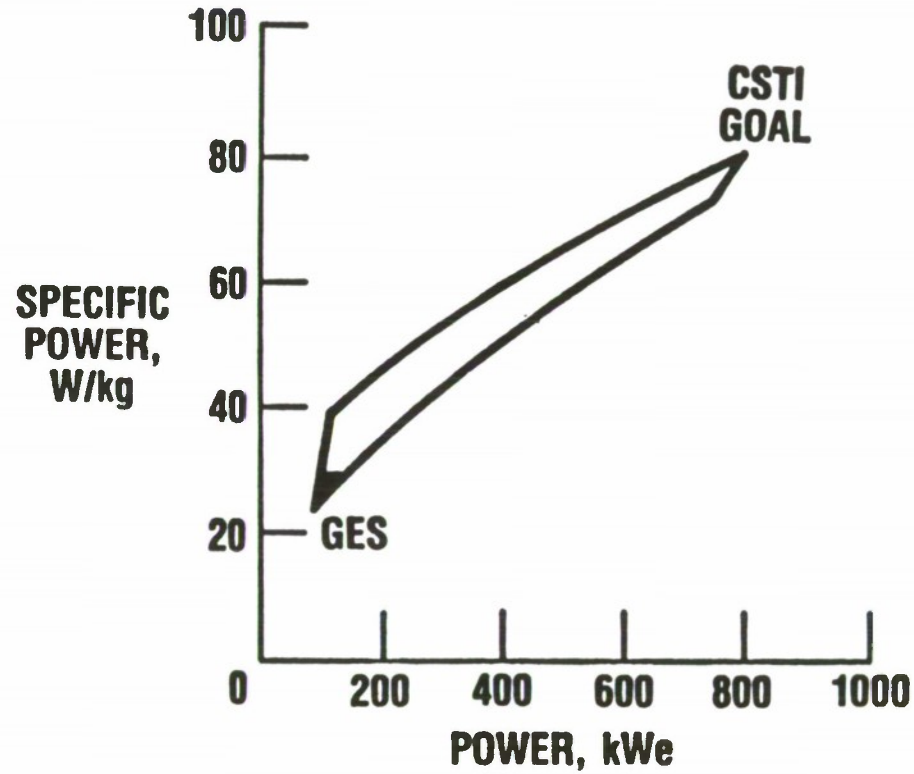
  25 → 80 W/kg
  100 → 800 kWe

- ADVANCED ENERGY CONVERSION
  - FREE PISTON STIRLING ENGINES
  - ADVANCED THERMOELECTRICS

- ADVANCED RADIATORS

- POWER CONDITIONING & CONTROL

- REFRACTORY & COMPOSITE MATERIALS



OASST

CSTI HIGH CAPACITY POWER MAJOR MILESTONES FY92

- **DEMONSTRATE TECH. READINESS $\Rightarrow$ 1300 k FPSE**
  - 1050 k (25%, <6kg/kWe, 25kWe/pl, T_R= 2.0)
  - 1 YEAR ENDURANCE
  - COMPONENT PERF. W/REFRACTORY METALS
- **Z = 1.2 Si Ge GaP "n" LEG TECH. AVAIL. FOR GES**
  - OA Z = 0.85
  - DEMONSTRATE POT. FOR Z = 1.2 COUPLE
- **850k, 550k HT PIPE DEMO., ε >0.85, <5kg/m^2**
  - ADV. RADIATOR DEMO. ~ 5kg/m^2
- **10^8 RAD. HARD, 400C INVERTER DEMO.**
- **COMPLETE REFRACTORY COMPOSITE CHARACTERIZATIONS**
- **POTENTIAL FOR 10 YEAR LIFE**

RJS88-007.16

OAST

CSTI

HIGH CAPACITY POWER

- **NASA CENTERS**

  LeRC - PROJECT MANAGEMENT - J. WINTER
  - ALL PROGRAM ELEMENTS

  JPL - ADVANCED THERMOELECTRICS - C. WOOD

RJS.9-13.016

CONCLUDING REMARKS

- **COMPREHENSIVE SPACE POWER PROGRAM**
  - BASE R&T, CSTI, PATHFINDER
  - SIGNIFICANT ACCOMPLISHMENTS
- **WELL CO-ORDINATED**
  - SDIO, USAF, DOE
  - LEVERAGE AT NATIONAL LEVEL
- **POWER SYSTEM CAPABILITY**
  - ENABLE BOLD NEW MISSIONS
  - RESTORE NATIONAL TECHNICAL LEADERSHIP
- **WE HOPE YOU CAN PARTICIPATE**

RJS.9-13.019

HUMANS IN SPACE: LIFE SUPPORT

NASA
Ames Research Center

PHYSICAL/CHEMICAL CLOSED-LOOP LIFE SUPPORT

JAMES G. LAWLESS, PhD

CHIEF, ECOSYSTEM SCIENCE AND
TECHNOLOGY BRANCH

SEPTEMBER 13, 1988

HUMANS IN SPACE: LIFE SUPPORT

NASA
Ames Research Center

PROGRAM OBJECTIVES

- PROVIDE A PHYSICAL/CHEMICAL LIFE SUPPORT TECHNOLOGY BASE TO ENABLE FUTURE LONG DURATION HUMAN SPACE MISSIONS
- PROVIDE AGENCY FOCUS FOR A MULTI-CENTER PHYSICAL/CHEMICAL LIFE SUPPORT R AND T PROGRAM
- ESTABLISH A PHYSICAL/CHEMICAL LIFE SUPPORT R AND T DEVELOPMENT INFRASTRUCTURE AMONG NASA, INDUSTRY AND UNIVERSITIES

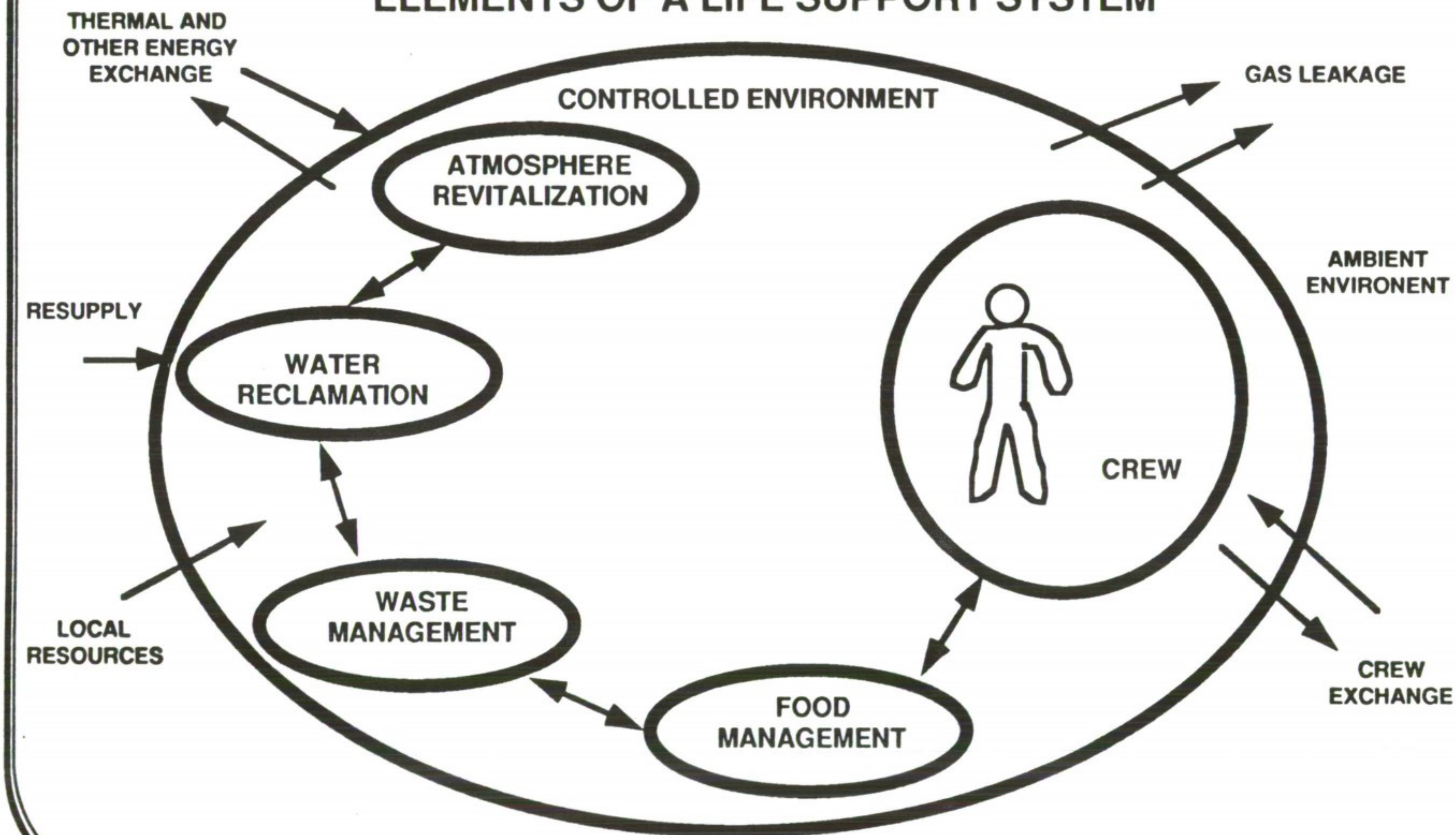
JUSTIFICATION

CLOSURE OF AIR & WATER LOOPS HAS THE POTENTIAL FOR AN ORDER OF MAGNITUDE REDUCTION IN THE MASS OF LIFE SUPPORT EXPENDABLES AND ASSOCIATED TRANSPORTATION REQUIREMENTS

HUMANS IN SPACE: LIFE SUPPORT

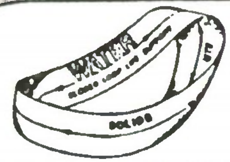
NASA
Ames Research Center

ELEMENTS OF A LIFE SUPPORT SYSTEM



IMPLEMENTATION

- BASE R & T
- PATHFINDER

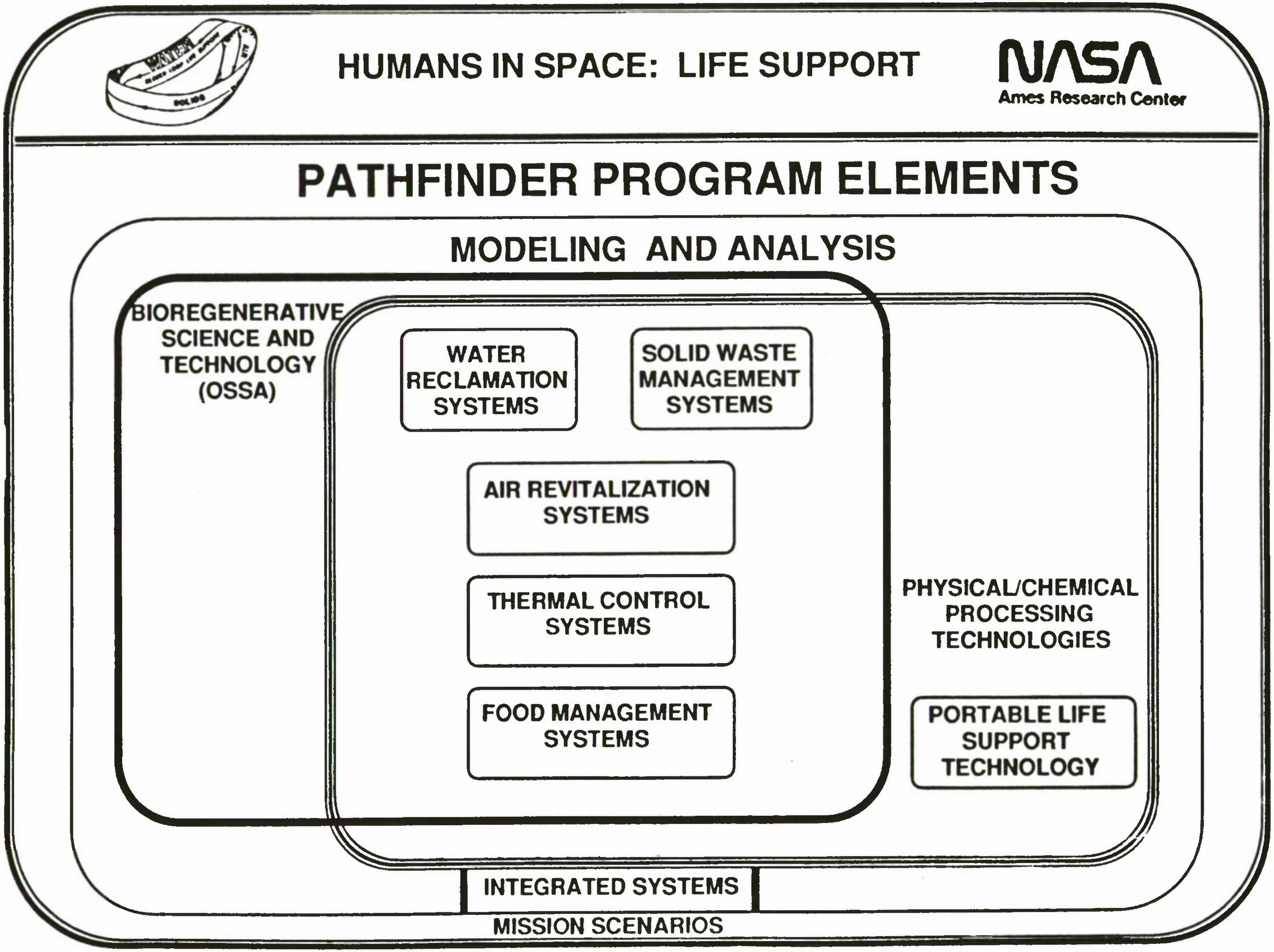


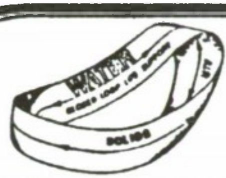
HUMANS IN SPACE: LIFE SUPPORT

NASA
Ames Research Center

R & T BASE PROGRAM

- AIR, WATER, WASTE PROCESSING RESEARCH
- PROCESS SIMULATION TECHNIQUES
- MONITORING AND CONTROL INSTRUMENTATION FOR AIR, WATER QUALITY, AND CONTAMINATION


HUMANS IN SPACE: LIFE SUPPORT
NASA
Ames Research Center
PATHFINDER PROGRAM ELEMENTS
MODELING AND ANALYSIS
BIOREGENERATIVE SCIENCE AND TECHNOLOGY (OSSA)
WATER RECLAMATION SYSTEMS
SOLID WASTE MANAGEMENT SYSTEMS
AIR REVITALIZATION SYSTEMS
THERMAL CONTROL SYSTEMS
FOOD MANAGEMENT SYSTEMS
PHYSICAL/CHEMICAL PROCESSING TECHNOLOGIES
PORTABLE LIFE SUPPORT TECHNOLOGY
INTEGRATED SYSTEMS
MISSION SCENARIOS



HUMANS IN SPACE: LIFE SUPPORT

NASA
Ames Research Center

MAJOR THRUSTS

WATER RECLAMATION

- Processing technology
- Contaminant control
- Subsystem analytical modeling & validation

WASTE MANAGEMENT

- Composition and definition
- Handling & processing
- Subsystem analytical modeling & validation

AIR REVITALIZATION

- CO2 removal
- Oxygen generation
- Trace contaminant control
- Subsystem analytical modeling & validation

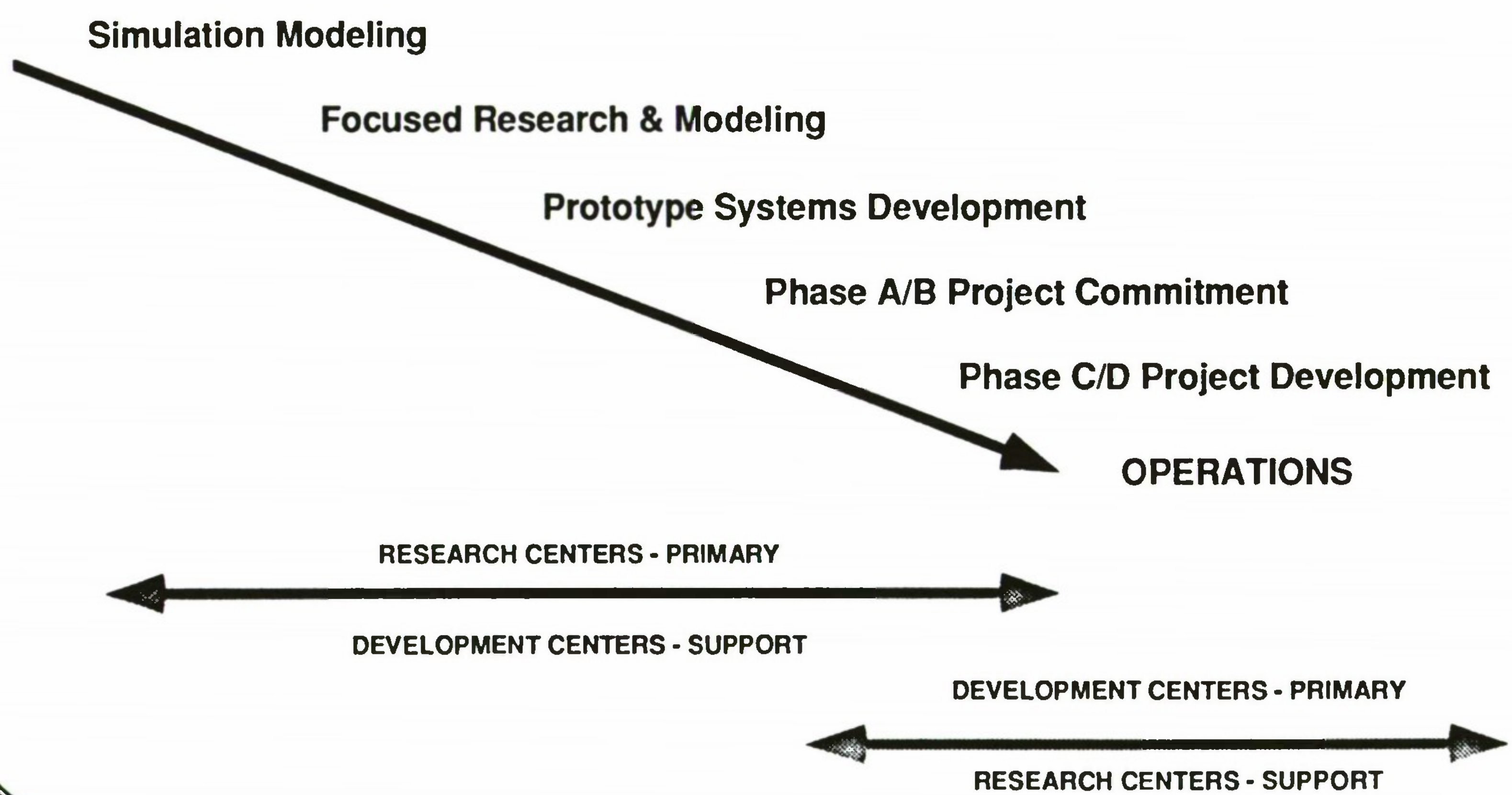
INTEGRATED SYSTEMS

- System requirements
- Systems analysis & assessment
- System test & validation

HUMANS IN SPACE: LIFE SUPPORT

NASA Ames Research Center

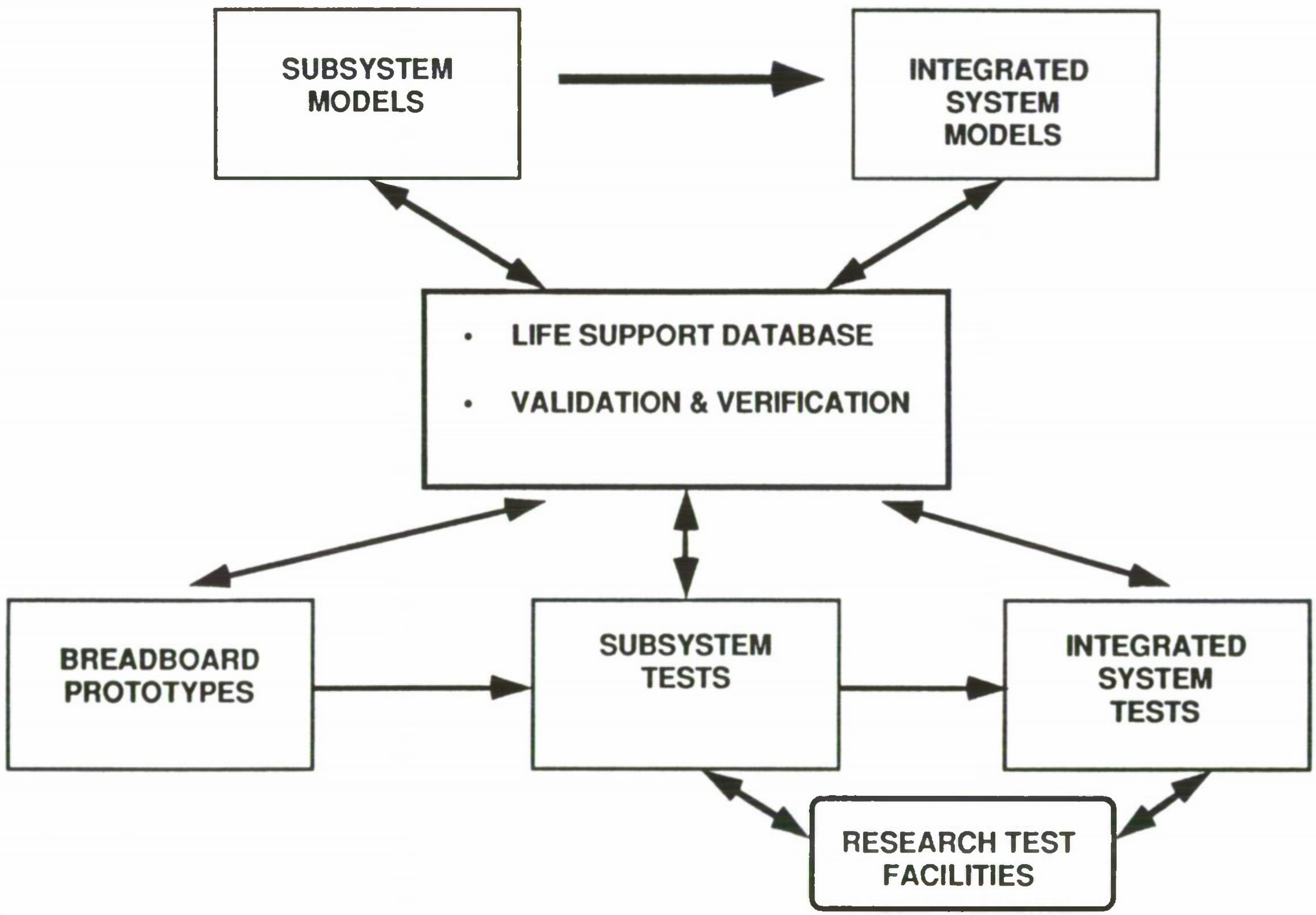
Pathfinder P/C Closed Loop Life Support Technology Development



HUMANS IN SPACE: LIFE SUPPORT

NASA
Ames Research Center

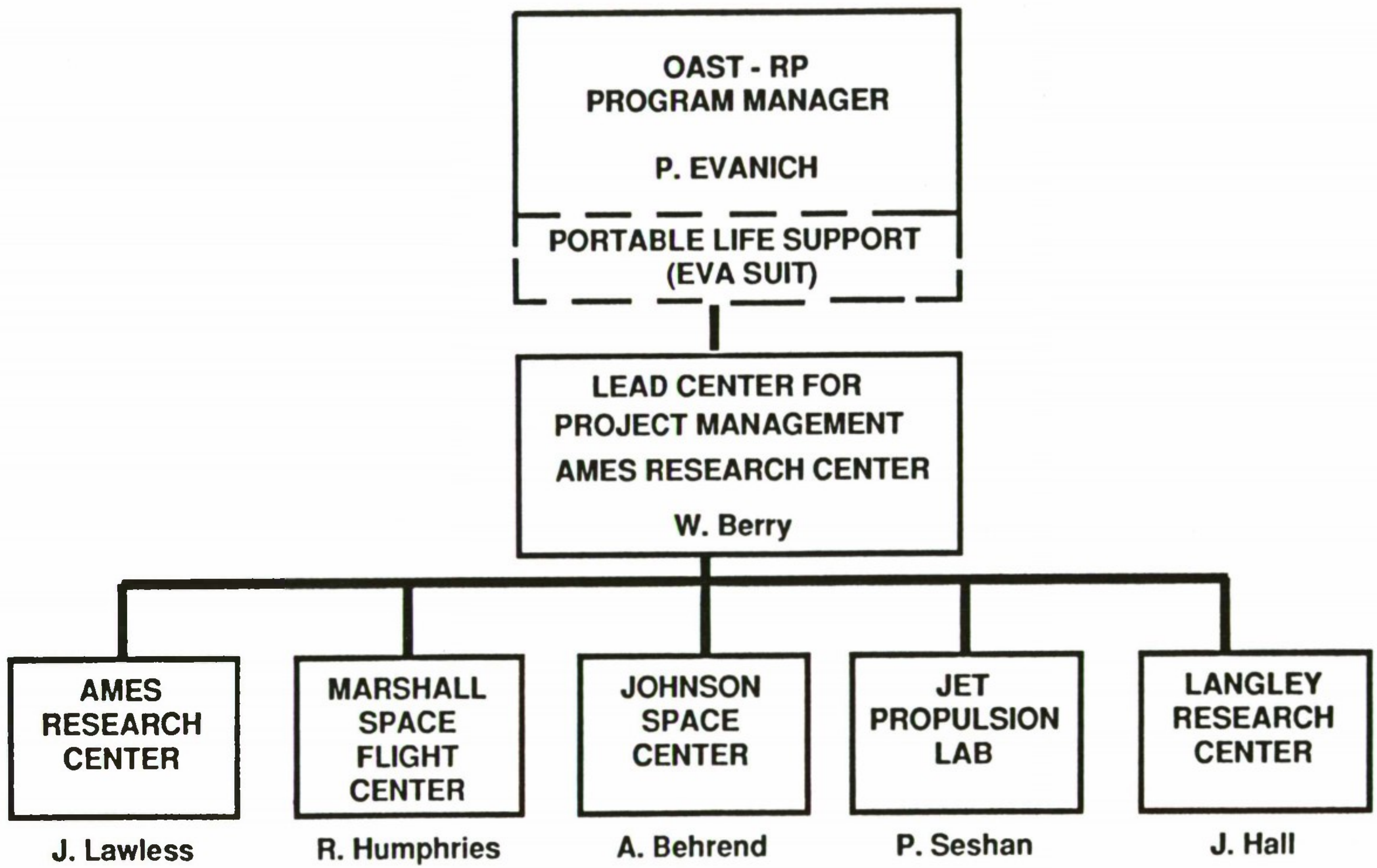
TECHNICAL APPROACH



HUMANS IN SPACE: LIFE SUPPORT

NASA Ames Research Center

P/C CLOSED LOOP LIFE SUPPORT PROGRAM



PATHFINDER P/C CLOSED LOOP LIFE SUPPORT

MAJOR DELIVERABLES

	89	90	91	92
WATER RECLAMATION	Assessment		Validated Process	Technologies
WASTE MANAGEMENT	Subsystem Selection			Model Development Analysis
AIR REVITALIZATION		Subsystem Selection		Initiate Integrat. Analysis
INTEGRATED SYSTEMS	System Requirements			Subsystem Prototype Design Packages

Office of
Aeronautics and
Space
Technology

INFORMATION SCIENCES AND
HUMAN FACTORS DIVISION

PROGRAM OVERVIEW

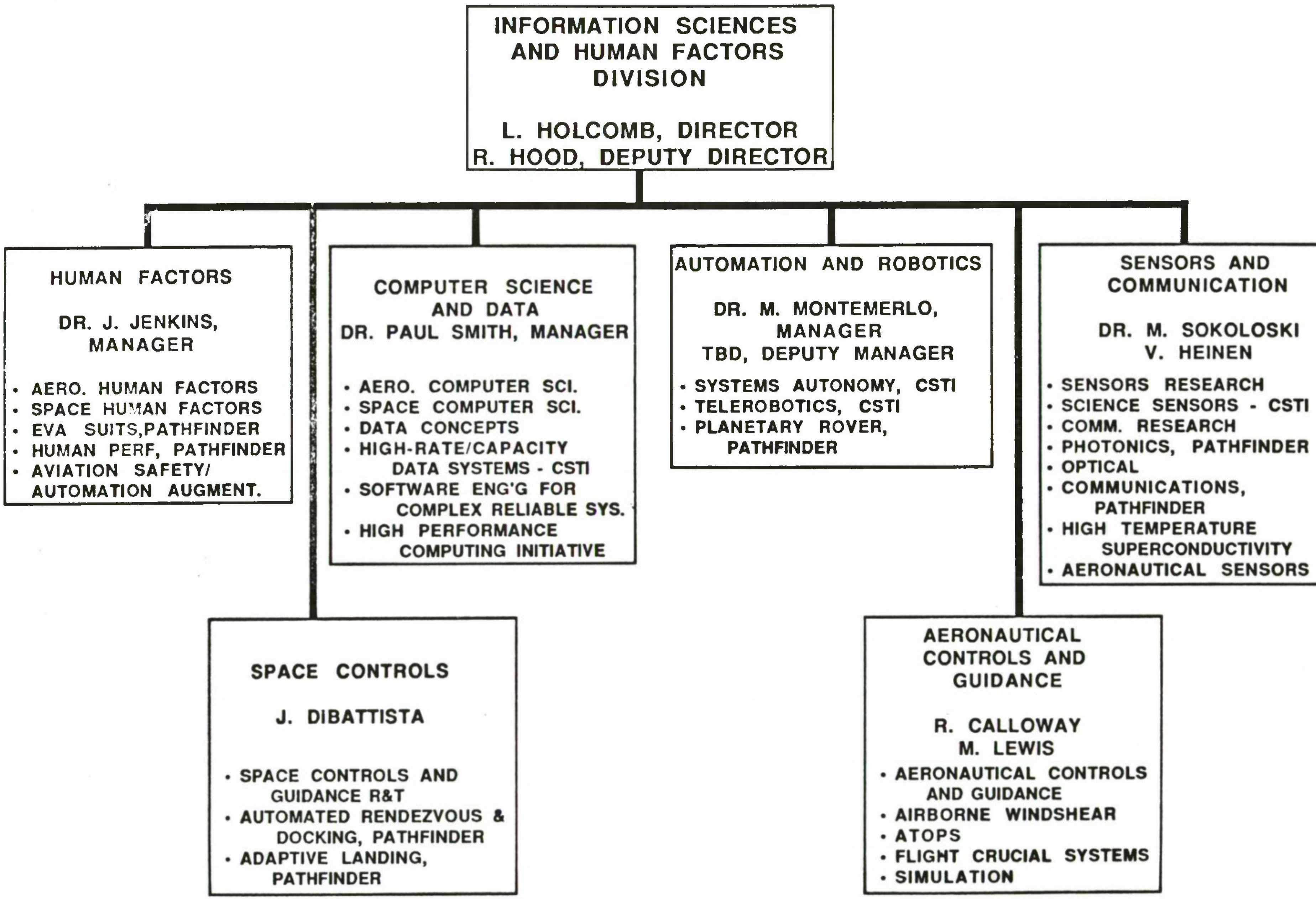
Presentation to

AIAA/OAST SPACE TECHNOLOGY CONFERENCE

Lee B. Holcomb
Director
September 13, 1988

INFORMATION SCIENCES AND HUMAN FACTORS DIVISION
ORGANIZATION

OAST



GOALS

OAST

1. EVOLVING SPACE TELEROBOTICS CAPABILITY
2. EVOLVING AUTOMATED SPACE SYSTEMS CAPBILITY
3. NASA-UNIQUE SPACE SENSING CONCEPTS
4. EFFICIENT ACQUISITION, PROCESSING, DISTRIBUTION AND ANALYSIS OF SPACE-DERIVED DATA
5. EFFECTIVE UTILIZATION OF HUMANS-IN-SPACE
6. ADVANCED SPACE COMMUNICATIONS CAPABILITY
7. CONTROL OF COMPLEX/FLEXIBLE SPACE SYSTSMS
8. RELIABLE AND ADAPTIVE GUIDANCE, NAVIGATION AND CONTROL OF ADVANCED TRANSPORTATION VEHICLES

DISCIPLINARY CROSSWALK

O-A-S-T

	GOAL							
R&T BASE	1	2	3	4	5	6	7	8
SPACE DATA & COMM. R&T								
SOFTWARE ENGINEERING								●
ADV. DATA CONCEPTS				◒				
COMMUNICATIONS						●		
INFORMATION SCIENCES R&T								
COMPUTER SCIENCES				●				
SENSORS		◒						
PHOTONICS		○						
CONTROLS & GUIDANCE R&T								
CONTROL TECHNOLOGY							●	
GUIDANCE CONCEPTS								●
COMPUTATIONAL CONTROLS							●	
HUMAN FACTORS R&T								
CREWSTATION DESIGN					●			
EXTRAVEHICULAR ACTIVITY					●			
CSTI								
AUTOMATION & ROBOTICS								
ROBOTICS	●							
AUTONOMOUS SYSTEMS		●						
INFORMATION TECHNOLOGY								
SCIENCE SENSOR TECHNOLOGY			●					
DATA: HIGH RATE/CAPACITY				●				
PATHFINDER								
EXPLORATION TECHNOLOGY								
PLANETARY ROVER	●							
OPTICAL COMMUNICATIONS						●		
OPERATIONS TECHNOLOGY								
AUTOMATED RENDEZ. & DOCKING								●
HUMANS-IN-SPACE								
EXTRAVEHICULAR ACTIVITY/SUIT					●			
HUMAN PERFORMANCE					●			
TRANSFER VEHICLE TECHNOLOGY								
AUTONOMOUS LANDER								●
FAULT-TOL. SYS. (PHOTONICS)			●					

TELEROBOTICS

OAST

LONG RANGE GOAL:

TO PROVIDE AND VALIDATE THE BASIC TECHNOLOGY TO ACHIEVE SUCCESSFULLY HIGHER LEVELS OF SPACE ROBOTIC CAPABILITY

THRUSTS:

- TELEROBOTIC DEMONSTRATIONS
- SENSING AND PERCEPTION
- PLANNING AND REASONING
- CONTROL EXECUTION
- OPERATOR INTERFACE

FY 88 ACCOMPLISHMENTS:

- EASE STRUCTURE ASSEMBLY BY BAT
- FORCE CONTROL OF MULTI ARM MANIPULATOR
- TELEROBOTIC INTERACTIVE PLANNING SYSTEM
- AUTOMATED VISION-BASED SATELLITE GRAPPLING
- TELEROBOTIC INTELLIGENT INTERFACE FLIGHT EXPERIMENT

FY 89 PROGRAM FOCUS

- SHARED HUMAN/AUTOMATION CONTROL TELEROBOTIC DEMONSTRATION
- SUPPORT OF SATELLITE SERVICING CAPABILITY
- INITIATION OF NEW APPLICATIONS DEMOS: SHUTTLE RMS AND UMBILICAL
- INITIATION OF PLANETARY ROVER
- CONTINUED CORE TECHNOLOGY

LONG RANGE MILESTONES:

SYSTEMS AUTONOMY

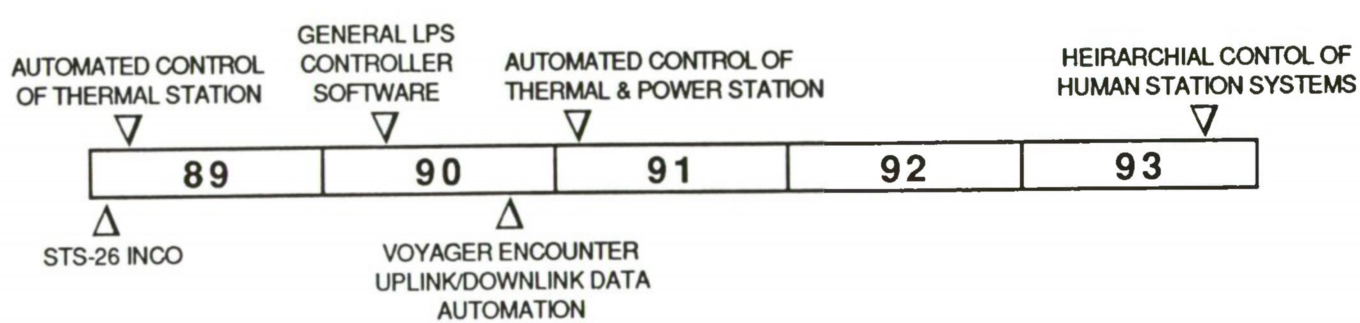
LONG RANGE GOAL:
TO PROVIDE AND VALIDATE THE BASIC TECHNOLOGY TO ACHIEVE SUCCESSIVELY HIGHER LEVELS OF AUTONOMY IN SPACE OPERATIONS

THRUSTS:
- SYSTEMS AUTONOMY DEMONSTRATIONS
- ARTIFICIAL INTELLIGENCE
- SYSTEM ARCHITECTURE AND INTEGRATION

FY 88 ACCOMPLISHMENTS:
- SHUTTLE INTEGRATED COMMUNICATIONS OFFICER REAL-TIME EXPERT SYSTEM
- SPACE STATION THERMAL CONTROL EXPERT SYSTEM EVALUATED ON BRASSBOARD
- INITIAL PLANNING FOR COMBINED SPACE STATION THERMAL AND POWER SYSTEMS
- MACHINE LEARNING APPLIED TO ANALYSIS OF INFRARED ASTRONOMY DATA

FY 89 PROGRAM FOCUS
- SPACE STATION SYSTEM AUTONOMY DEMONSTRATIONS
- REAL-TIME EXPERT SYSTEM CONTROL OF SHUTTLE LAUNCH PROCESSING SYSTEMS
- HUBBLE SPACE TELESCOPE DESIGN/ENGINEERING KNOWLEDGE CAPTURE

LONG RANGE MILESTONES:



SPACE SENSORS

OAST

LONG RANGE GOAL:

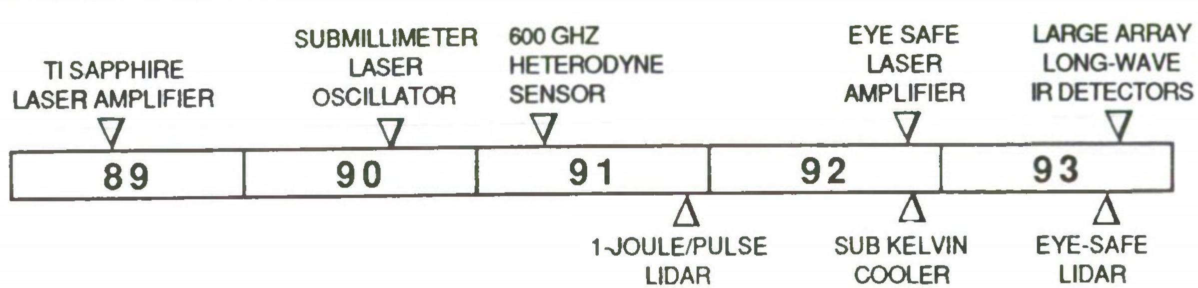
TO PROVIDE SPACE QUALIFIABLE TECHNOLOGY FOR THE EFFECTIVE AND EFFICIENT DETECTION OF ELECTROMAGNETIC RADIATION FROM THE MILLIMETER TO THE GAMMA-RAY WAVELENGTH REGION

THRUSTS:
- DETECTOR SENSORS
- SUBMMW SENSORS
- LIDAR SENSORS
- COOLER SYSTEMS
- SOLID STATE TECHNOLOGY (INCLUDING PHOTONICS)

FY 88 ACCOMPLISHMENTS:
- EXCELLENT LOW-BACKGROUND IR ARRAY PERFORMANCE
- HELIUM-3 COOLER (0.25°K) FOR ROCKET-BORNE IR EXPERIMENTS
- DIODE-PUMPED Nd:YAG SPACE LASER FOR RANGING AND ALTIMETRY
- IMAGING X-RAY AND COSMIC RAY SPECTROMETERS
- SUBMILLIMETER OSCILLATORS DEMONSTRATED AT
- SOLID-STATE LASER DESIGN DATA BASE

FY89 PROGRAM FOCUS:
- SOLID-STATE LASER TECHNOLOGY
- LONG-LIFE, STABLE 10-JOULE-PER-PULSE (CO_2) SPACE LASER FOR LASER ATMOSPHERIC WIND SOUNDER
- HUBBLE SPACE TELESCOPE DESIGN/ENG'G KNOWLEDGE CAPTURE
- COMPONENTS FOR 600-3000 GHZ SUB-mm SENSORS
- INCOHERENT DETECTORS FOR IR, UV, X-RAY & COSMIC RAY SENSORS

LONG RANGE MILESTONES:



HUMANS IN SPACE

OAST

LONG RANGE GOAL:

TO PROVIDE GUIDELINES, METHODS AND TECHNOLOGY TO ASSURE THE SAFE AND EFFECTIVE UTILIZATION OF HUMANS IN SPACE

THRUSTS:

- HUMAN PERFORMANCE
- HUMAN/INTELLIGENT SYSTEM INTERFACE
- SENSORY AND INFORMATION FUSION
- EVA SYSTEMS

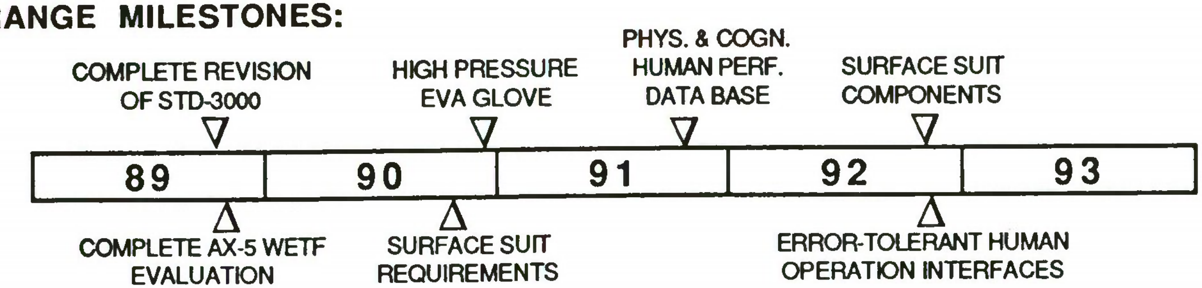
FY 88 ACCOMPLISHMENTS:

- ADVANCED HARD SPACE SUIT STRENGTH/MOTION TESTING IN WETF
- VIRTUAL WORKSTATION
- EVA HELMET MOUNTED DISPLAY PROTOTYPE
- HUMAN INTERFACE TO THERMAL EXPERT SYSTEM
- PYRAMID IMAGE CODES DEVELOPED FOR HUMAN DISPLAY INTERFACES AND FOR ROBUST COMPUTER VISION

FY89 PROGRAM FOCUS:

- STUDY OF HUMAN FACTORS IMPLICATION IN NASA'S OPERATIONAL EXPERIENCE
- EVALUATION OF HARD SUIT AND GLOVES FOR EVA
- EVALUATION OF VIRTUAL WORKSTATION FOR TELEROBOTIC CONTROL AND "EXPLORATION" OF PLANETARY SURFACES
- INITIATION OF SURFACE SUIT AND HUMAN PERFORMANCE ELEMENTS OF PATHFINDER

LONG RANGE MILESTONES:



SPACE COMMUNICATIONS

OAST

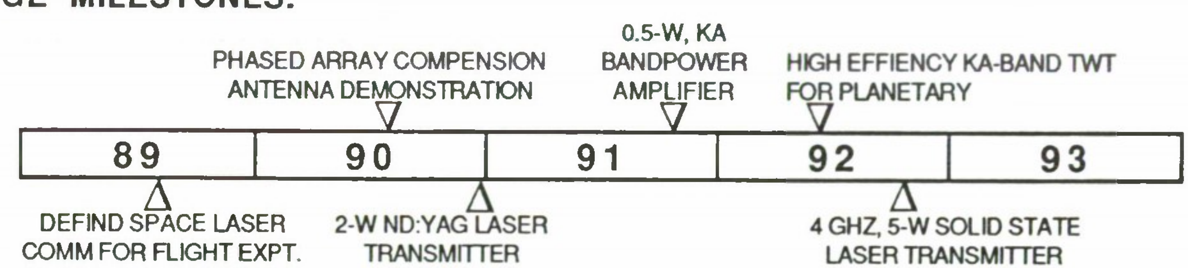
LONG RANGE GOAL:
DEVELOP DEVICES, COMPONENTS & ANALYTICAL METHODS TO SUPPORT THE COMM. RQMTS. OF NASA'S FUTURE NEAR-EARTH, DEEP-SPACE & SPACE STATION MISSIONS

THRUSTS:
- HIGH EFFICIENCY TUBES
- SOLID STATE DEVICES
- LARGE ANTENNAS
- OPTICAL COMMUNICATIONS

FY 88 ACCOMPLISHMENTS:
- Ka-BAND MMIC POWER AMPLIFIER FOR DEEP SPACE MISSIONS
- SPACE ANTENNA DISTORTION COMPENSATION BY ADAPTIVE ELECTRONIC FEED
- HIGH-EFFICIENCY DEEP SPACE OPTICAL COMMUNICATIONS LASER
- PHASED-ARRAY SEMICONDUCTOR LASER
- NEAR-EARTH LASER TRANSMITTER AND RECEIVER
- HIGH-EFFICIENCY X-BAND TWT FOR MARS OBSERVER

FY89 PROGRAM FOCUS:
- HIGH-FREQUENCY, HIGH-EFFICIENCY TWTS
- COMPENSATION FOR FLEXIBLE SPACE ANTENNAS
- HIGH-DATA-RATE EARTH ORBIT AND PLANETARY
- SPACE LASER COMMUNICATIONS
- HIGH-EFFICIENCY MMIC TECHNOLOGY FOR PLANETARY COMMUNICATIONS

LONG RANGE MILESTONES:



SPACE DATA SYSTEMS

OAST

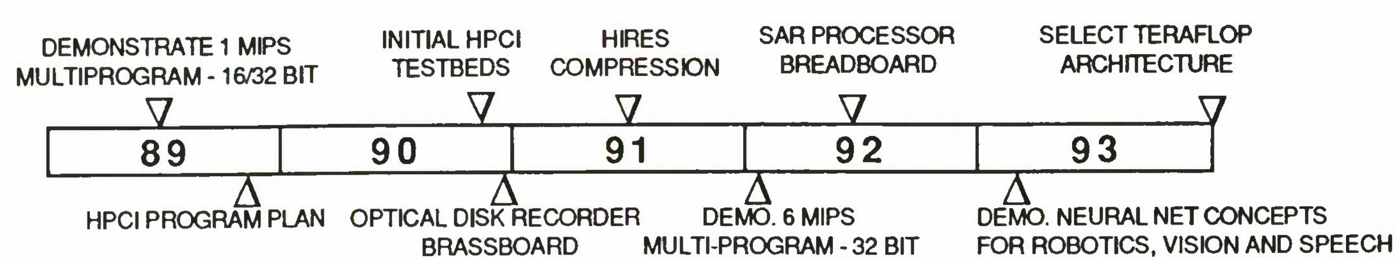
LONG RANGE GOAL:
TO PROVIDE AGENCY FOUNDATION IN FUNDAMENTAL AEROSPACE COMPUTER SCIENCE TO ENABLE EFFICIENT AND EFFECTIVE ACQUISITION, PROCESSING, DISTRIBUTION AND ANALYSIS OF SPACE-DERIVED INFORMATION

THRUSTS:
- CONCURRENT PROCESSING
- INFORMATION MANAGEMENT
- ADVANCED ATA CONCEPTS
- ON-BOARD PROCESSING TECHNIQUES
- HIGH PERFORMANCE STORAGE TECHNOLOGY

FY 88 ACCOMPLISHMENTS:
- ESTABLISHMENT OF CENTER OF EXCELLENCE IN SPACE DATA AND INFORMATION SCIENCES AT THE UNIVERSITY OF MARYLAND AND GSFC
- DEMONSTRATED REVERSIBLE, VAR. STRENGTH ELECTRONIC "NEURAL NETWORK" DEVICE
- DEVELOPED HARDWARE SIMULATOR OF SPARSE DISTRIBUTED NETWORK
- COMPLETED DESIGN FOR REAL-TIME FOCAL PLANE PROCESSOR FOR HIGH RESOLUTION IMAGING SPECTROMETER
- DEMONSTRATED FEASIBILITY OF OPTICAL NEED, LASER DIODES AND MEDIA FOR TERABIT ERASIBLE OPTICAL DISK RECORDER

FY 89 PROGRAM FOCUS:
- NEURAL NETWORK RESEARCH
- ON-BOARD PROCESSING SYSTEMS
- MODULAR TERABIT OPTICAL DISK BRASSBOARD
- PLAN HIGH PERFORMANCE COMPUTING INITIATIVE (HPCI)

LONG RANGE MILESTONES:



TRANSPORTATION VEHICLE GUIDANCE AND CONTROL

OAST

LONG RANGE GOAL:

TO PROVIDE COST EFFECTIVE, RELIABLE AVIONICS FOR ADVANCED EARTH-TO-ORBIT TRANSFER AND PLANETARY VEHICLES

THRUSTS:

- FAULT TOLERANT PROCESSING
- SOFTWARE ENGINEERING
- ADAPTIVE G, N. AND C CONCEPTS
- SENSORS AND ACTUATORS

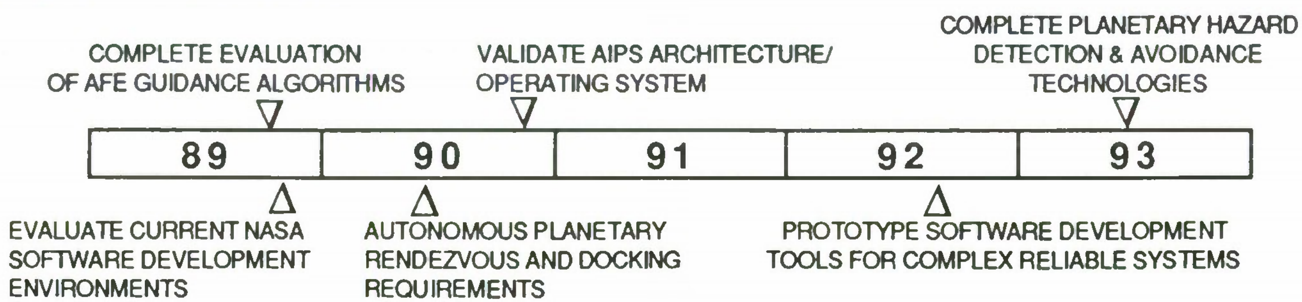
FY 88 ACCOMPLISHMENTS:

- ADVANCED 8-COMPONENT FIBER OPTIC GYRO BREADBOARD
- INCREASED "QUIET TIME" FOR AFE
- LANDING ANALYSIS FOR MARS SAMPLE RETURN MISSION
- IMPACT OF ADA ON FLIGHT CONTROL
- EVALUATION OF AIPS FAULT-TOLERANT PROCESSOR
- EMPIRICAL COMPARISON OF FAULT TOLERANCE AND FAULT ELIMINATION

FY89 PROGRAM FOCUS:

- VALIDATION OF AIPS OPERATING SOFTWARE
- AUTOMATED RENDEZVOUS AND DOCKING, PATHFINDER
- ADAPTIVE LANDING, PATHFINDER
- SOFTWARE ENGINEERING FOR COMPLEX RELIABLE SYSTEMS

LONG RANGE MILESTONES:



SPACECRAFT CONTROL

OAST

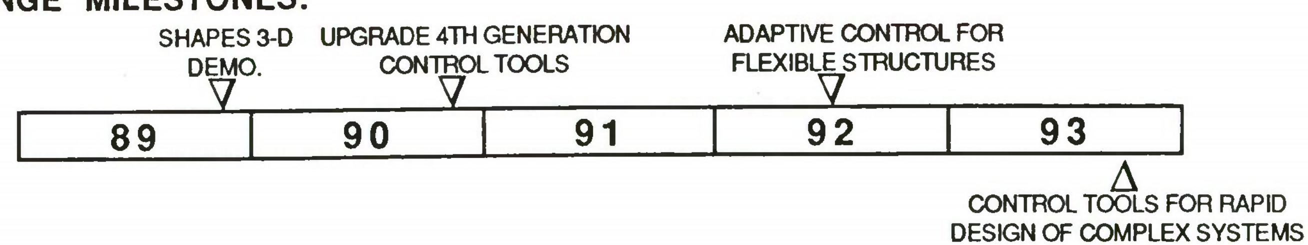
LONG RANGE GOAL:
TO PROVIDE THE CONTROL ALGORITHMS, COMPUTATIONAL METHODS, AND SYSTEMS MODELS TO ENABLE THE CONTROL OF COMPLEX/FLEXIBLE SPACE SYSTEMS

THRUSTS:
- COMPUTATIONAL CONTROL
- ADVANCED CONTROL
- CONTROL OF FLEXIBLE STRUCTURES
- CONTROL OF LARGE APERATURE SEGMENTED OPTICS/INTERFEROMETERS

FY 89 ACCOMPLISHMENTS
- CONTROL TECHNIQUES EVALUATED ON ADVANCED CONTROL EVALUATION FOR STRUCTURES (ACES)-1 TEST ARTICLE
- NON-LINEAR, MULTI-BODY COMPUTER ANALYSIS TOOL ENHANCEMENTS
- COMPUTATIONALLY EFFICIENT CONTROL TECHNIQUES EVALUATED ON SPACECRAFT
- CONTROL LABORATORY EXPERIMENT (SCOLE)
- LQG CONTROL FOR THE MINI-MAST EXPERIMENT
- COMPLETED DESIGN FOR 3-D SHAPES BREADBOARD AND DETAILED PERFORMANCE CHARACTERIZATION

FY 89 PROGRAM FOCUS
- CONTROL OF FLEXIBLE STRUCTURES; LARGE ANTENNAS AND PLATFORMS
- CONTROL OF PRECISION OPTICAL SYSTEMS
- COMPUTATIONAL METHODS FOR MULTI-BODY CONTROL

LONG RANGE MILESTONES:



INFORMATION SCIENCES AND HUMAN FACTORS DIVISION

MAJOR PROGRAM DIRECTIONS IN SPACE

OAST

GENERAL

- INCREASE UNIVERSITY RESEARCH BLOCK GRANTS
- INCREASE PROGRAM OFFICE AND INDUSTRY INVOLVEMENT IN CSTI AND PATHFINDER ELEMEN
- EXPLIOT OPPORTUNITIES OF PHOTONICS AND HIGH-TEMPERATURE SUPERCONDUCTIVITY
- INCREASE EMPHASIS ON SPACE FLIGHT EXPERIMENTS

EVOLVING SPACE ROBOTIC CAPABILITY:

- MAINTAIN LONG-TERM TECHNOLOGY BASE
- TRANSFER INITIAL DEMONSTRATION RESULTS/CAPABILITY TO FTS AND SATELLITE SERVICING CONCEPTS
- INCREASED EMPHASIS ON APPLICATIONS DEMONSTRATIONS AND TECHNOLOGY FLIGHT EXPERIMENTS
- INITIATE PLANETARY ROVER PROGRAM

INTELLIGENT SYSTEMS RESEARCH:

- MAINTAIN NATIONAL REPUTATION IN ARTIFICIAL INTELLIGENCE RESEARCH
- PERFORM EFFECTIVE GROUND-BASED DEMONSTRATIONS FOR SPACE STATION, SHUTTLE AND SCIENCE MISSIONS
- INITIATE RESEARCH TO MERGE INTELLIGENT SYSTEMS WITH EXPLORATION VEHICLES

INFORMATION SCIENCES AND HUMAN FACTORS DIVISION

MAJOR PROGRAM DIRECTIONS IN SPACE

OAST

NASA-UNIQUE SPACE SENSING CONCEPTS:

- ADDRESS NASA-UNIQUE DETECTOR REQUIREMENTS IN CSTI SCIENCE SENSORS PROGRAM
  - LOW-BACKGROUND INFRARED DETECTORS
  - SUBMILLIMETER SENSORS
  - ACTIVE LASER SENSING
- INITIATE NEW THRUST IN SCIENCE SENSORS AND OPTICS FOR GLOBAL CHANGE

ADVANCED SPACE COMMUNICATIONS CAPABILITY:

- CONTINUE TWT, SOLID STATE MMIC DEVICE AND ANTENNA RESEARCH
- INCREASE SUPPORT TO NEAR-EARTH AND PLANETARY OPTICAL COMMUNICATIONS

EFFICIENT ACQUISITION, PROCESSING, DISTRIBUTION AND ANALYSIS OF SPACE DERIVED DATA:

- MAINTAIN STRONG COMPUTER SCIENCE PROGRAM IN COST-EFFECTIVE SOFTWARE, CONCURRENT PROCESSING AND INFORMATION MANAGEMENT
- IMPLEMENT CSTI HIGH-RATE/CAPACITY DATA PROGRAM
- INITIATE NEW INITIATIVE IN HIGH PERFORMANCE COMPUTING

INFORMATION SCIENCES AND HUMAN FACTORS DIVISION
MAJOR PROGRAM DIRECTIONS IN SPACE

OAST

EFFECTIVE UTILIZATION OF HUMANS IN SPACE:
- FOCUS ON HUMAN-INTELLIGENT SYSTEM INTERFACE, SENSOR AND INFORMATION FUSION, AND EVA SYSTEMS
- INITIATE PATHFINDER EXTRAVEHICULAR ACTIVITY/SUIT AND HUMAN PERFORMANCE PROGRAM ELEMENTS

CONTROL OF COMPLEX/FLEXIBLE SPACE SYSTEMS:
- SUPPORT CONTROL STRUCTURES INTERACTION RESEARCH
- INITIATE RESEARCH FOR CONTROL OF PRECISION OPTICS
- INITIATE COMPUTATIONAL CONTROLS RESEARCH PROGRAM

GUIDANCE, NAVIGATION AND CONTROL TECHNOLOGY FOR TRANSPORTATION VEHICLES:
- SUPPORT REAL-TIME FAULT TOLERANT CONTROL ARCHITECTURE RESEARCH
- ADVOCATE FAULT TOLERANT FLIGHT SYSTEMS INITIATIVE
- IMPLEMENT NEW THRUST IN SOFTWARE ENGINEERING FOR COMPLEX RELIABLE SYSTEMS
- INITIATE PATHFINDER AUTONOMOUS LANDER AND AUTONOMOUS RENDEZVOUS AND DOCKING PROGRAM ELEMENTS

SYSTEMS AUTONOMY

Henry Lum, Jr.
Chief, Information Sciences Division
NASA Ames Research Center

TECHNOLOGY FOR FUTURE NASA MISSIONS

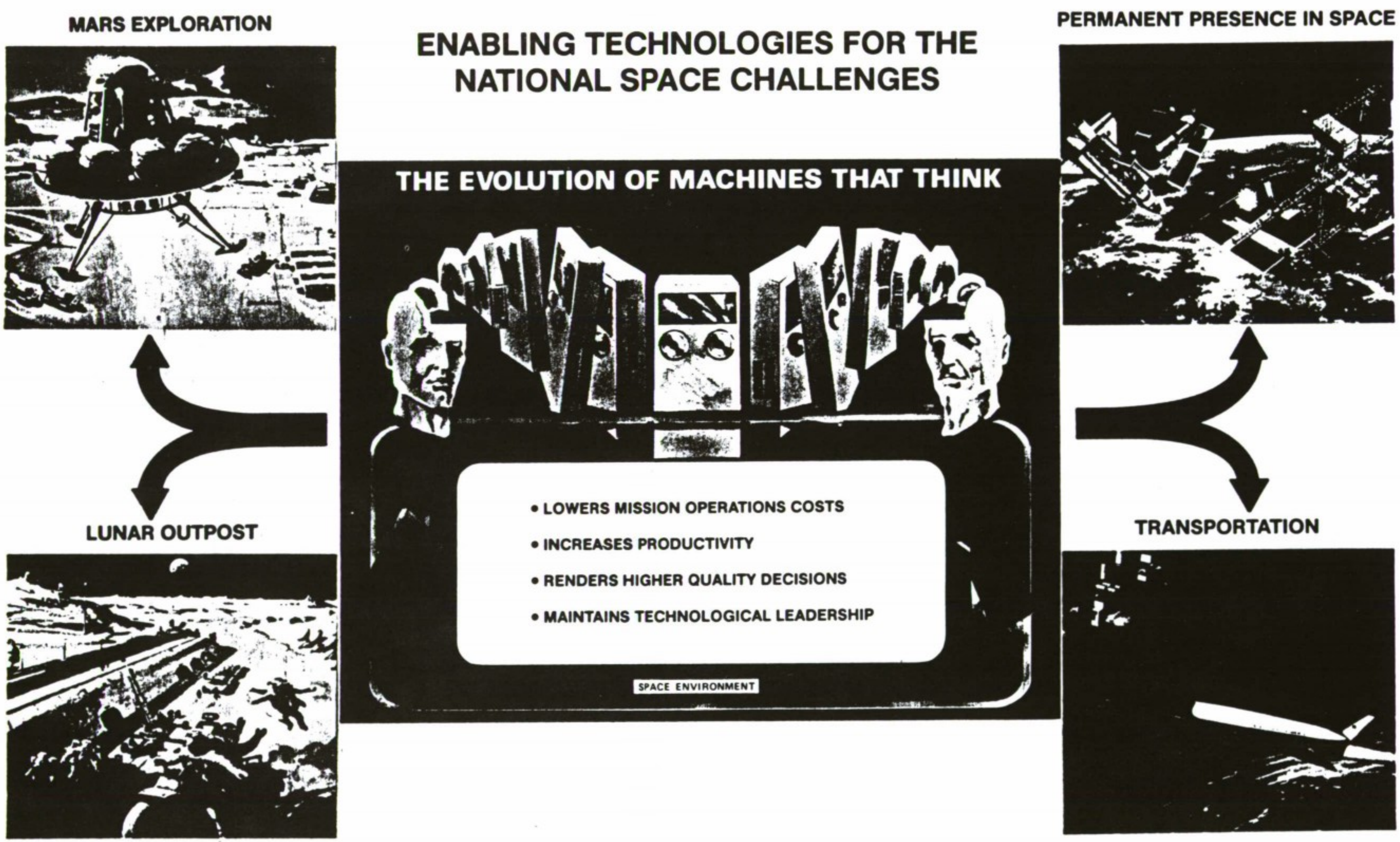
AN AIAA/OAST CONFERENCE
ON CSTI AND PATHFINDER

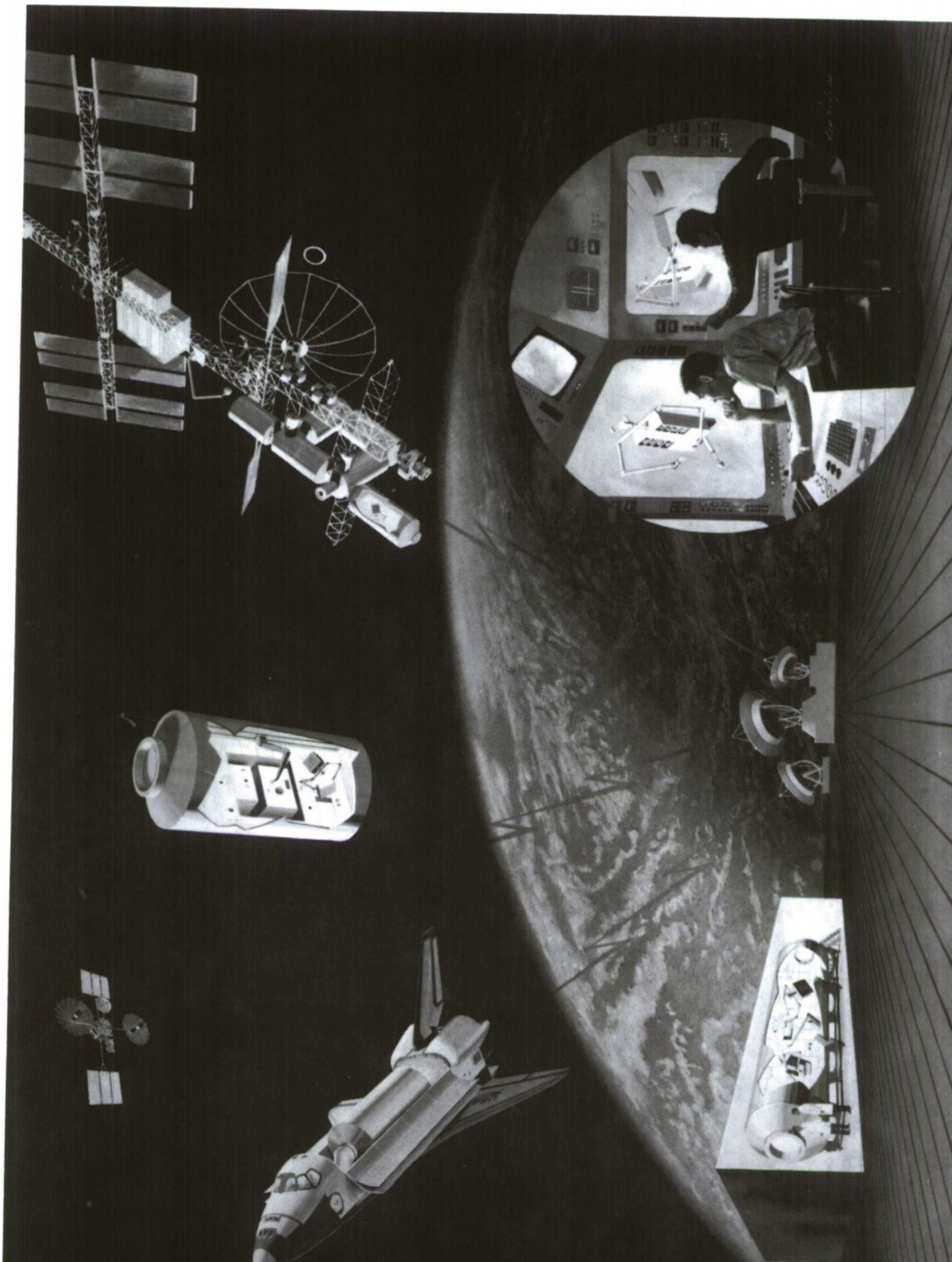
12-13 SEPTEMBER, 1988

WASHINGTON D.C.

SYSTEMS AUTONOMY PROGRAM

ENABLING TECHNOLOGIES FOR THE NATIONAL SPACE CHALLENGES





END-TO-END SYSTEMS INTEGRATION OF HUMANS, INTELLIGENT SYSTEMS, AND FACILITIES


Transportation
Operations
Humans-in-Space
Exploration

SYSTEMS AUTONOMY PROGRAM

WHY INTELLIGENT AUTONOMOUS SYSTEMS

REDUCE MISSION OPERATIONS COSTS

- AUTOMATE LABOR INTENSIVE OPERATIONS

INCREASE MISSION PRODUCTIVITY

- AUTOMATE ROUTINE ONBOARD HOUSEKEEPING FUNCTIONS

INCREASE MISSION SUCCESS PROBABILITY

- AUTOMATE REAL-TIME CONTINGENCY REPLANNING

HL/AIAA 9-88 (LAH)

DESCRIPTION OF INTELLIGENT AUTONOMOUS SYSTEMS

CHARACTERISTICS

KNOWLEDGE-BASED SYSTEMS

- DYNAMIC WORLD KNOWLEDGE ACQUISITION, UNDERSTANDING, AND EXECUTION OF COMMAND FUNCTIONS
- RELIABLE DECISIONS IN UNCERTAIN ENVIRONMENTS
- LEARNING ABILITY
- ALLOWS "GRACEFUL" RETURN TO HUMAN CONTROL

CAPABILITIES

GOAL-DRIVEN BEHAVIOR

- COMMUNICATE AT HIGH LEVELS WITH HUMANS AND OTHER MACHINES

"COLLABORATIVE" HUMAN-MACHINE INTERACTIONS

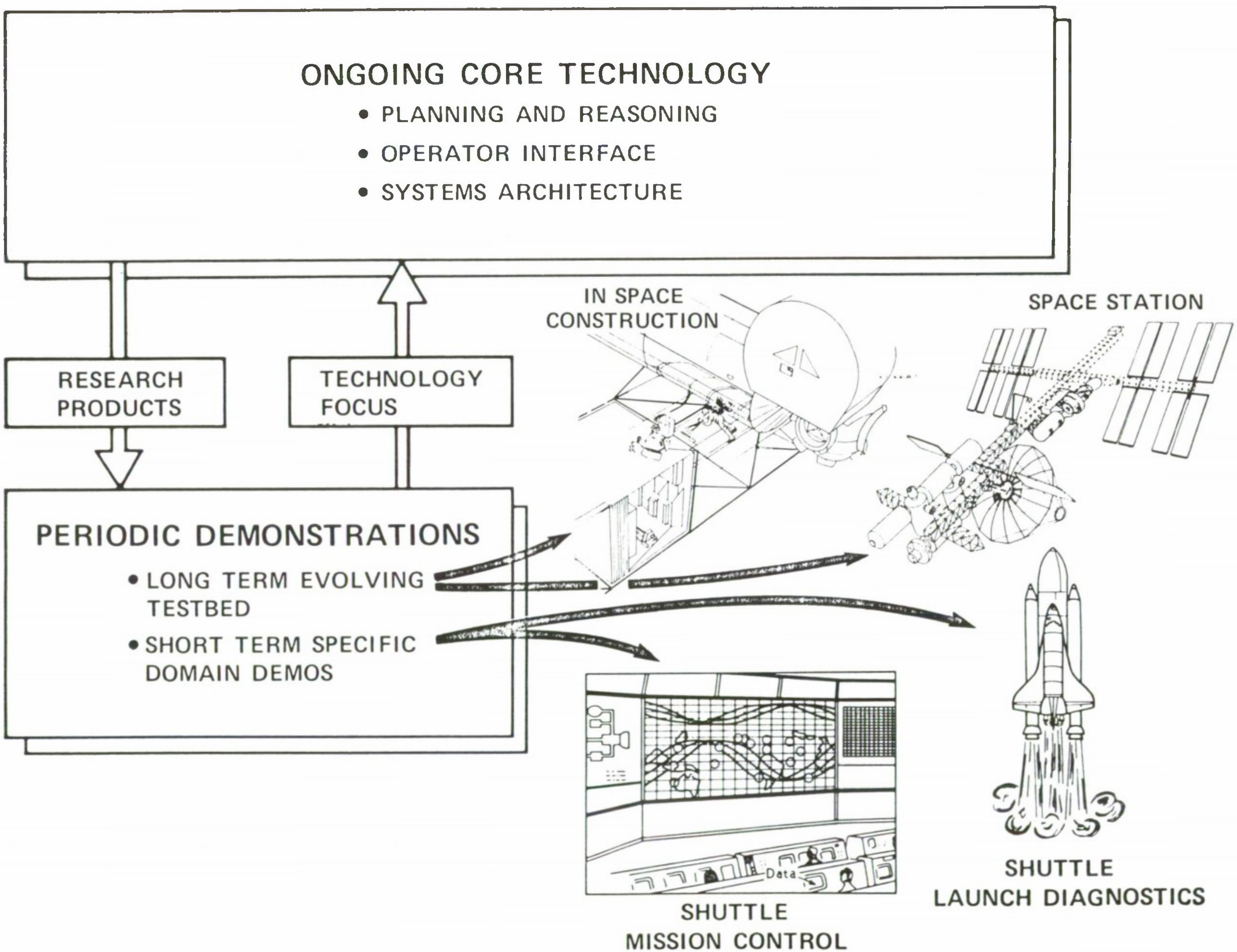
- RECOGNIZE AND RESOLVE COMMAND ERRORS

SELF-MAINTENANCE

- OPERATE AUTONOMOUSLY FOR EXTENDED PERIODS OF TIME

SYSTEMS AUTONOMY PROGRAM

HOW DO WE GET THERE - PROGRAM ELEMENTS



SYSTEMS AUTONOMY PROGRAM

TECHNICAL CHALLENGES

- REAL-TIME KNOWLEDGE-BASED SYSTEMS
- DYNAMIC KNOWLEDGE ACQUISITION AND UNDERSTANDING
- ROBUST PLANNING AND REASONING
- COOPERATING KNOWLEDGE-BASED SYSTEMS
- VALIDATION METHODOLOGIES

SYSTEMS AUTONOMY PROGRAM - TECHNOLOGICAL CHALLENGES

A. WHERE WE ARE TODAY

REAL-TIME KNOWLEDGE-BASED SYSTEMS
- NO PARALLEL SYMBOLIC-NUMERIC PROCESSORS
- SLOW SPECIAL-PURPOSE HARDWARE (1 GBYTE MEM, 5 MIPS)
- PROTOTYPING S/W SHELLS (ART, KEE, KNOWLEDGECRAFT)
- DIAGNOSIS AND PLANNING DECISIONS IN 1-10 MINUTES

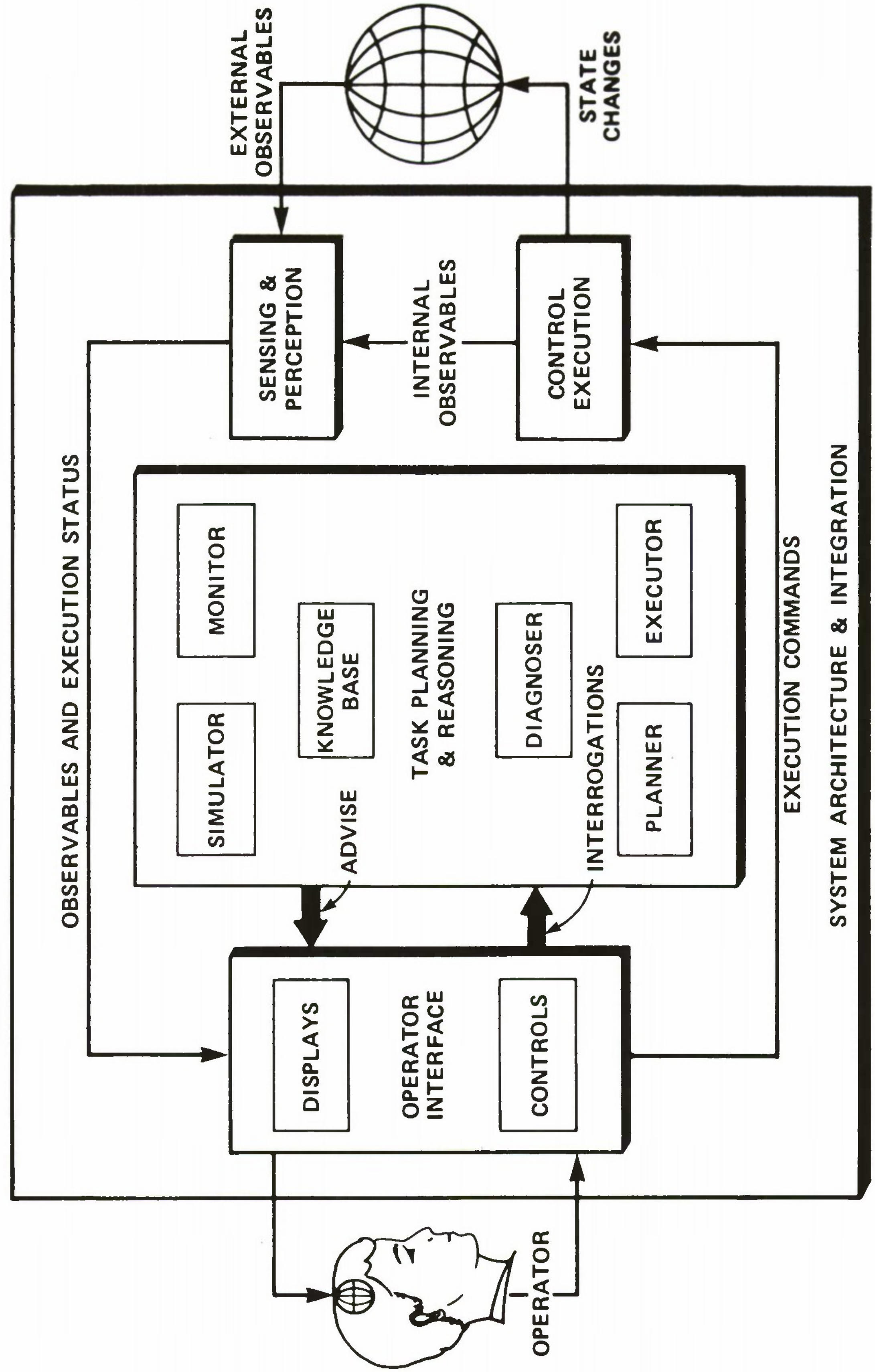
DYNAMIC KNOWLEDGE-ACQUISITION & UNDERSTANDING
- NO AUTOMATED EXPANSION OF K-B
- SMALL STATIC PRE-PROGRAMMED K-B
- DEC "XCON" LARGEST (5000 RULES, 2000 COMPONENTS)

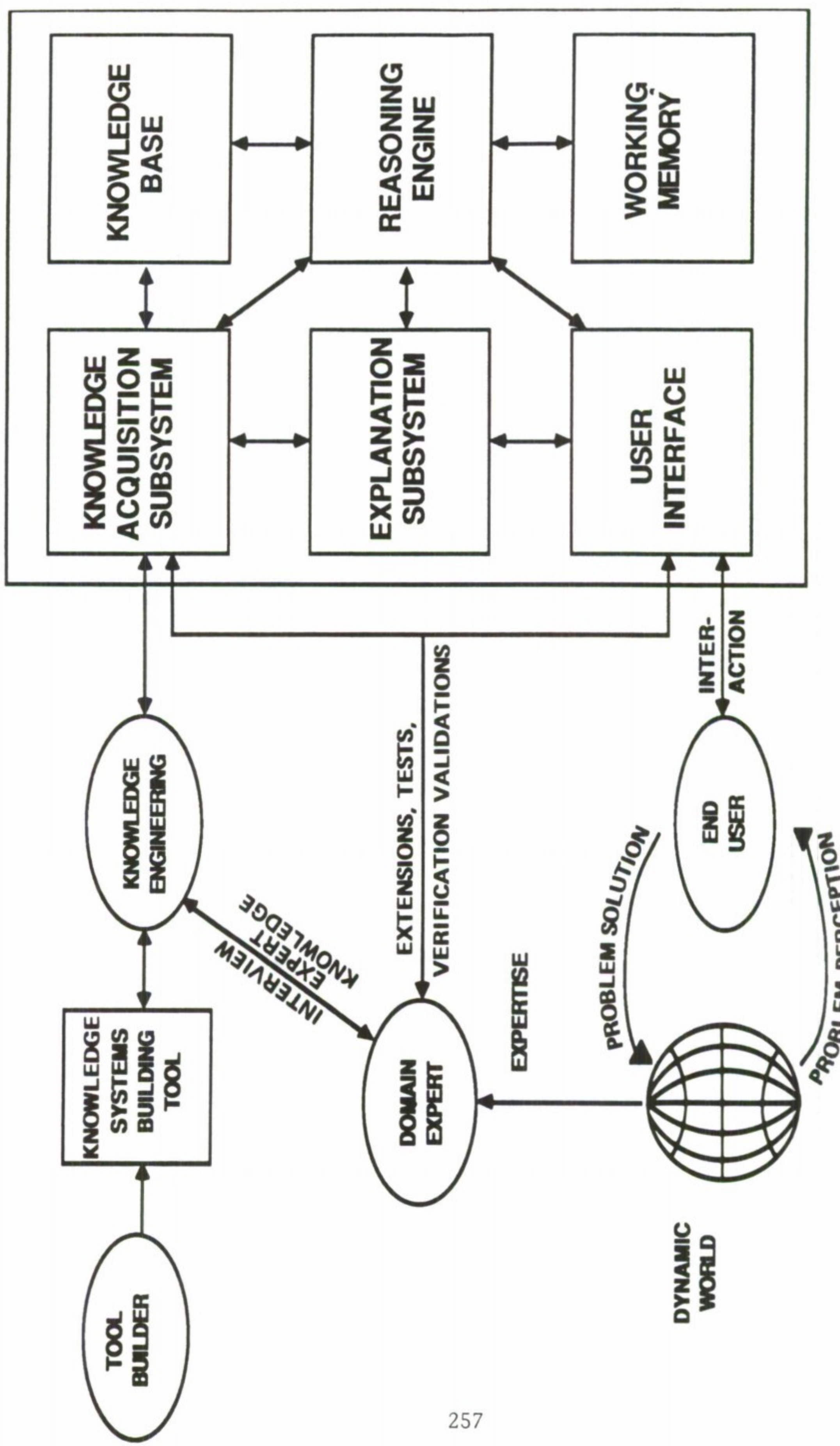
ROBUST PLANNING AND REASONING
- HEURISTIC RULES ONLY, NO CAUSAL MODELS
- PRE-MISSION PLANNING (NO REAL-TIME REPLANNING)
- DIAGNOSIS OF ONLY ANTICIPATED SINGLE FAULTS
- "FRAGILE" NARROW DOMAINS (RAPID BREAKDOWN AT K-B LIMITS)

COOPERATING KNOWLEDGE-BASED SYSTEMS
- SINGLE STANDALONE DOMAIN SPECIFIC SYSTEMS
- HUMAN INTERACTION ONLY, NO INTELLIGENT SYSTEMS INTERACTION

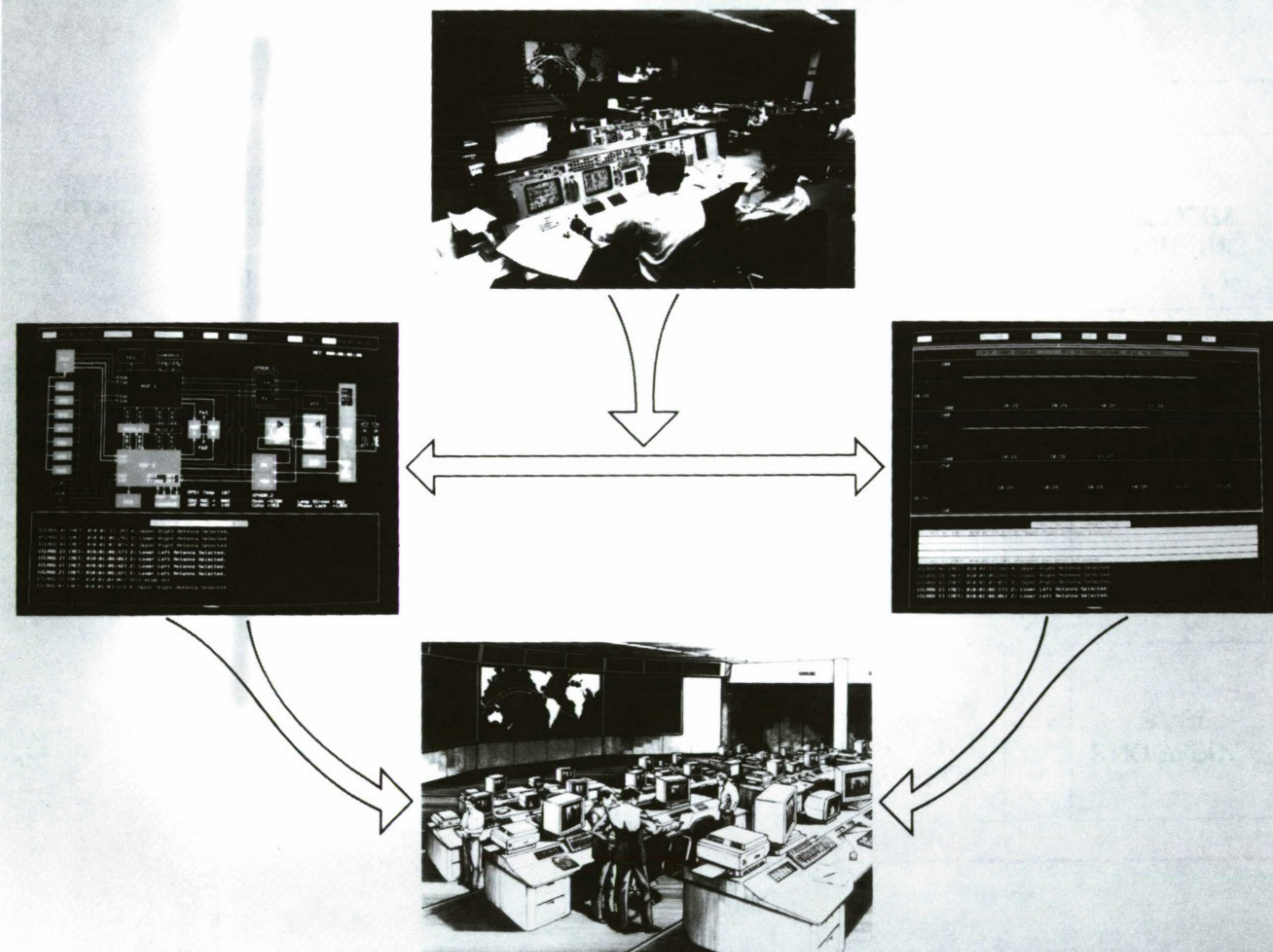
VALIDATION METHODOLOGIES
- CONVENTIONAL TECHNIQUES FOR ALGORITHMIC SYSTEMS

HL/AIAA 9-88 (LAH)

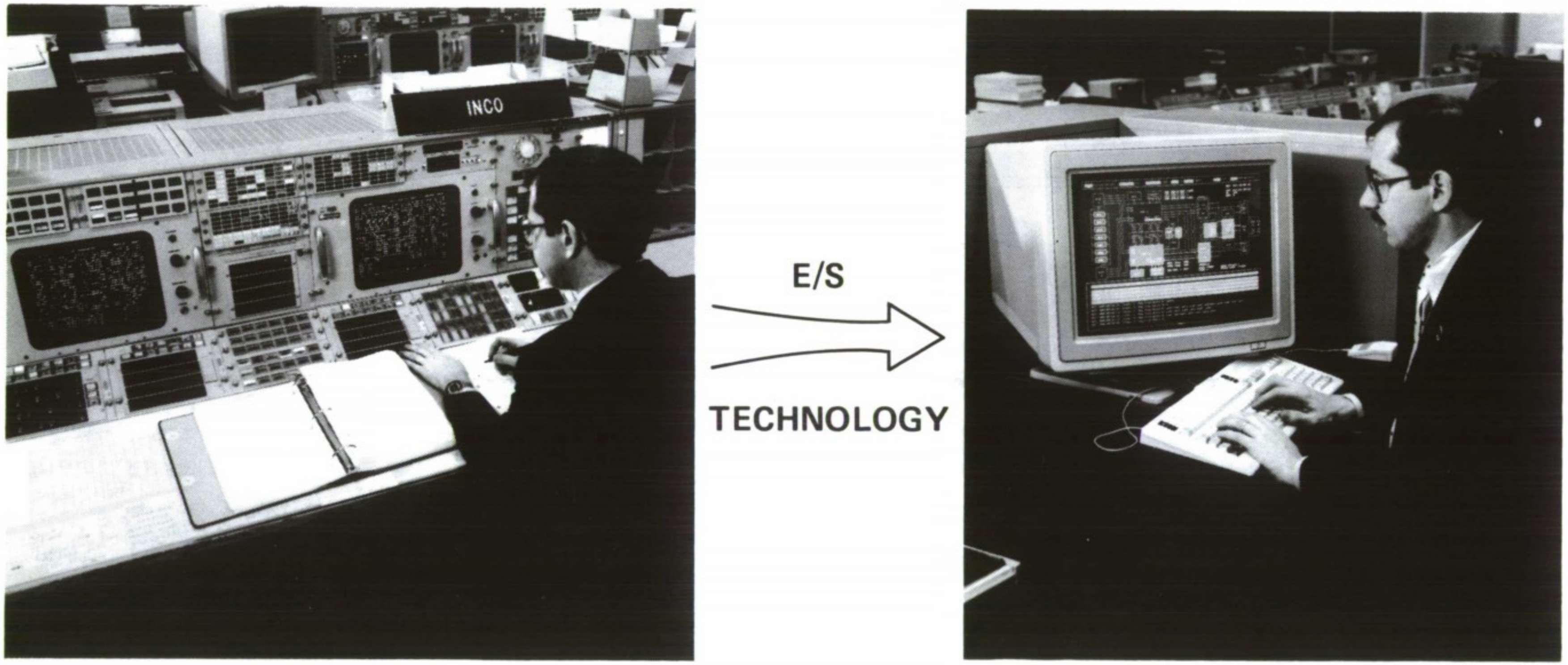

EXTERNAL OBSERVABLES
STATE CHANGES
SENSING & PERCEPTION
INTERNAL OBSERVABLES
CONTROL EXECUTION
OBSERVABLES AND EXECUTION STATUS
MONITOR
SIMULATOR
KNOWLEDGE BASE
TASK PLANNING & REASONING
DIAGNOSER
EXECUTOR
PLANNER
ADVISE
INTERROGATIONS
EXECUTION COMMANDS
SYSTEM ARCHITECTURE & INTEGRATION
DISPLAYS
OPERATOR INTERFACE
CONTROLS
OPERATOR


KNOWLEDGE BASE
REASONING ENGINE
WORKING MEMORY
KNOWLEDGE ACQUISITION SUBSYSTEM
EXPLANATION SUBSYSTEM
USER INTERFACE
KNOWLEDGE ENGINEERING
EXTENSIONS, TESTS, VERIFICATION VALIDATIONS
INTER-ACTION
END USER
INTERVIEW EXPERT KNOWLEDGE
EXPERTISE
PROBLEM SOLUTION
PROBLEM PERCEPTION
KNOWLEDGE SYSTEMS BUILDING TOOL
DOMAIN EXPERT
TOOL BUILDER
DYNAMIC WORLD

AUTOMATED SYSTEMS FOR IN-FLIGHT MISSION OPERATIONS
EVOLUTION OF AUTOMATION TECHNOLOGY



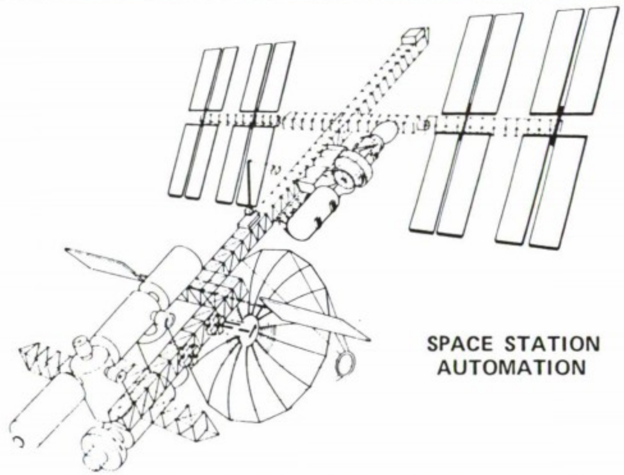
NASA AMES RESEARCH CENTER
OAST-SPONSORED RESEARCH



BEFORE NOW

SYSTEMS AUTONOMY PROGRAM DEMONSTRATION

SYSTEMS AUTONOMY DEMONSTRATION PROJECT (SADP)



SPACE STATION AUTOMATION

OBJECTIVES

DEMONSTRATE TECHNOLOGY FEASIBILITY OF INTELLIGENT AUTONOMOUS SYSTEMS FOR SPACE STATION THROUGH TESTBED DEMONSTRATIONS

- 1988: SINGLE SUBSYSTEM (THERMAL)
- 1990: TWO COOPERATING SUBSYSTEMS (THERMAL/POWER)
- 1993: HIERARCHICAL CONTROL OF SEVERAL SUBSYSTEMS
- 1996: DISTRIBUTED CONTROL OF MULTIPLE SUBSYSTEMS

PARTICIPANTS AND FACILITIES

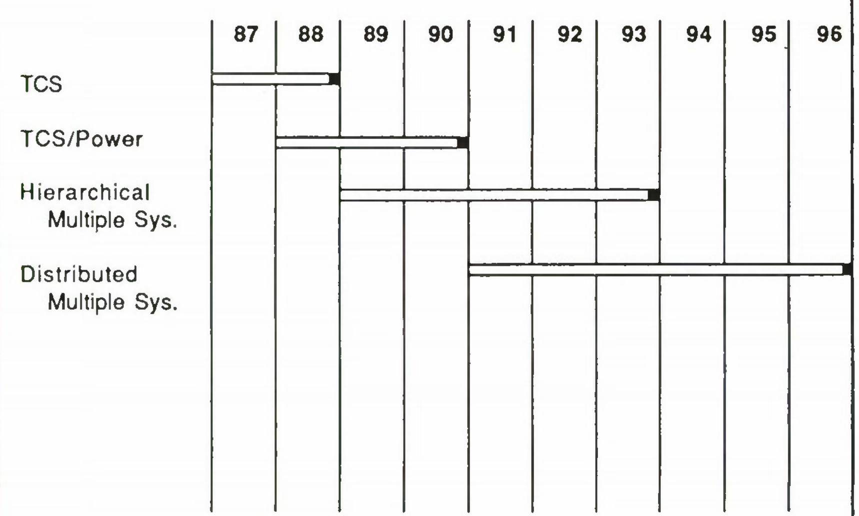
PARTICIPANTS

- AMES RESEARCH CENTER
- JOHNSON SPACE CENTER
- LEWIS RESEARCH CENTER
- MARSHALL SPACE FLIGHT CENTER
- INDUSTRY

FACILITIES

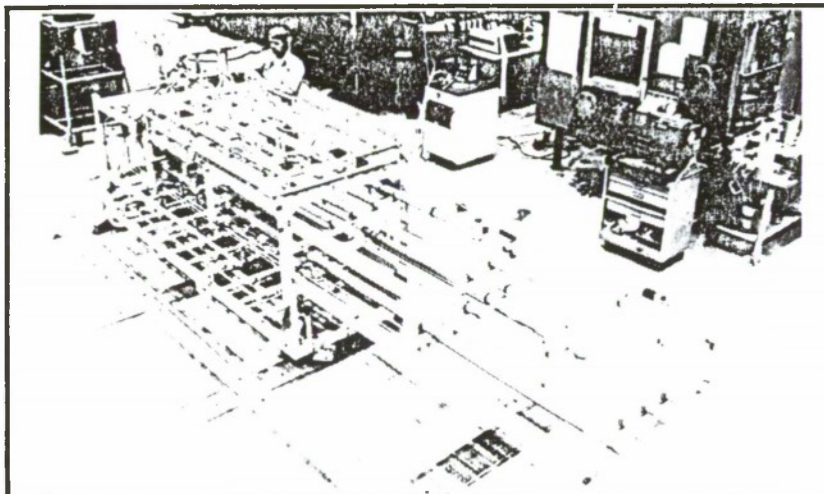
- ARC INTELLIGENT SYSTEMS LABORATORY
- JSC INTELLIGENT SYSTEMS LABORATORY
- JSC THERMAL TEST BED
- LeRC POWER TEST BED

SCHEDULE



HL/AIAA 9-88 (LAH)

1988 DEMONSTRATION
SYSTEMS AUTONOMY DEMONSTRATION PROJECT
SPACE STATION THERMAL CONTROL SYSTEM (TEXSYS)



OBJECTIVES

IMPLEMENTATION OF AI TECHNOLOGY INTO THE REAL-TIME DYNAMIC ENVIRONMENT OF A COMPLEX ELECTRICAL-MECHANICAL SPACE STATION SYSTEM - THE THERMAL CONTROL SYSTEM.

- REAL-TIME CONTROL
- FAULT DIAGNOSIS AND CORRECTION
- TREND ANALYSIS FOR INCIPIENT FAILURE PREVENTION
- INTELLIGENT HUMAN INTERFACE
- CAUSAL MODELLING
- VALIDATION TECHNIQUES

PARTICIPANTS AND FACILITIES

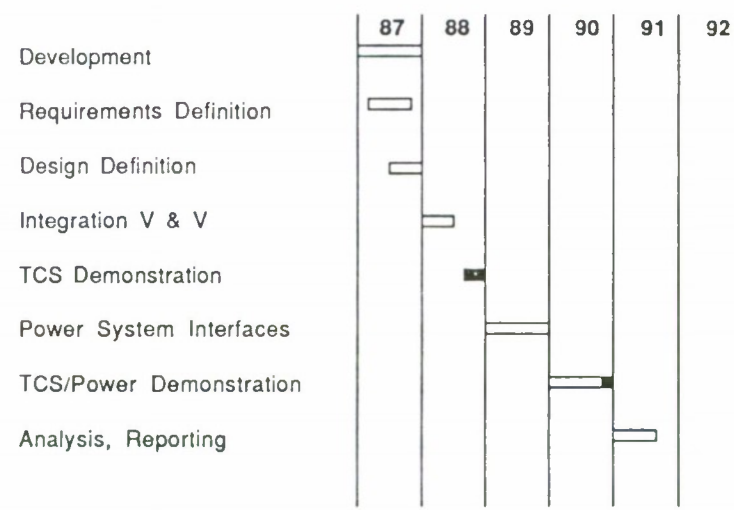
PARTICIPANTS

- AMES RESEARCH CENTER
- JOHNSON SPACE CENTER
- INDUSTRY: LEMSCO, ROCKWELL INTERNATIONAL, GEOCONTROL SYSTEMS, STERLING SOFTWARE

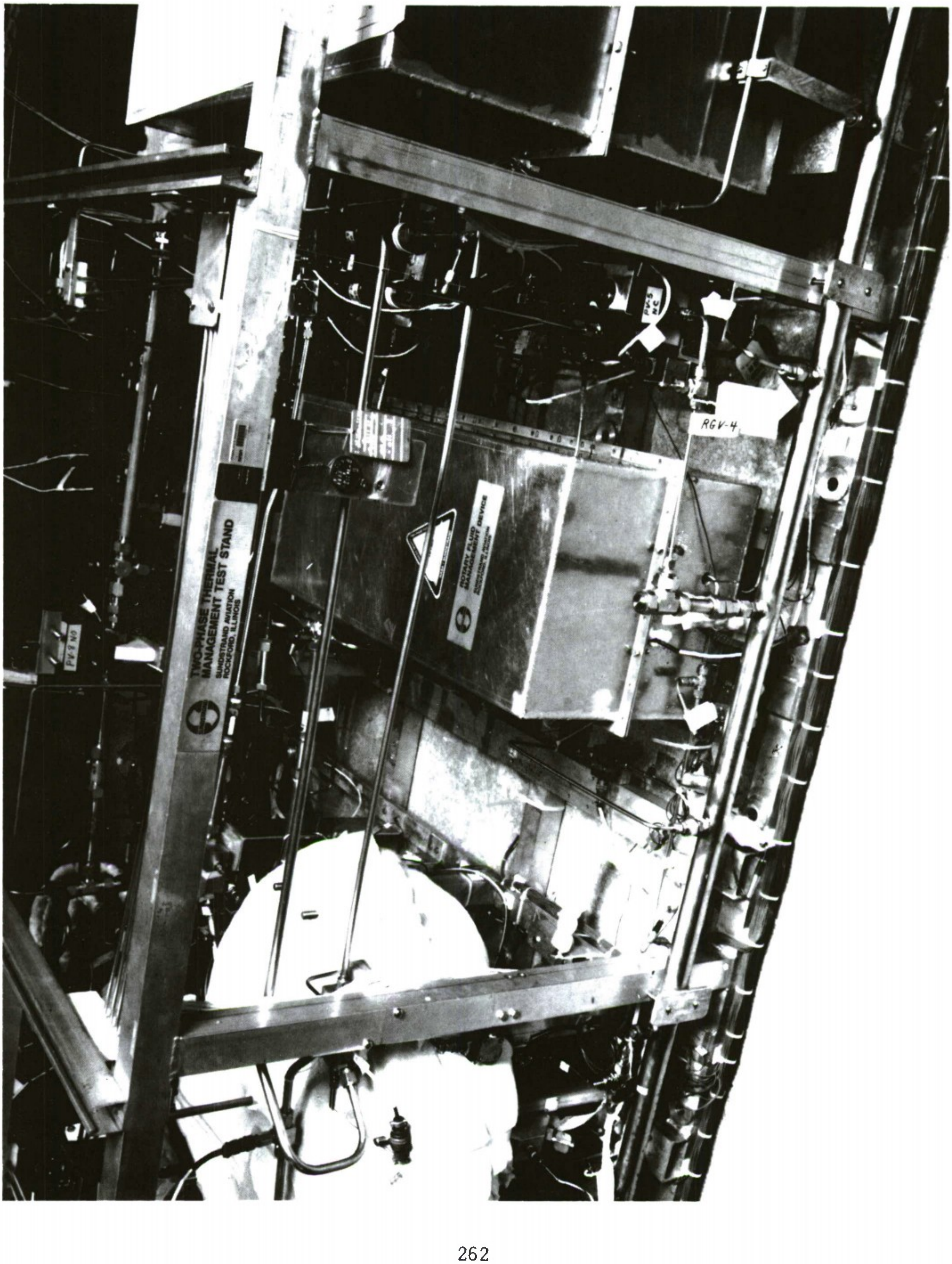
FACILITIES

- ARC INTELLIGENT SYSTEMS LABORATORY
- JSC INTELLIGENT SYSTEMS LABORATORY
- JSC THERMAL TEST BED

SCHEDULE



HL/AIAA 9-88 (LAH)


TWO-PHASE THERMAL
MANAGEMENT TEST STAND
SUNDSTRAND AVIATION
ROCKFORD, ILLINOIS
ROTARY FLUID
MANAGEMENT DEVICE
RGV-4

SYSTEM AUTONOMY DEMONSTRATION PROJECT

TCS FUNCTIONAL CAPABILITIES

PROTOTYPE OBJECTIVES	DEMO 1/87
CAUSAL MODELS/SIMULATION	●
LIMITED FAULT DIAGNOSIS	●

KNOWLEDGE BASE EXPANSION

DEMONSTRATION OBJECTIVES	1 6/87	2 9/87	3 12/87	4 2/88	5 5/88
NOMINAL REAL-TIME CONTROL	◍	◍	◍	●	●
FAULT DIAGNOSIS AND CORRECTION	◍	◍	◍	●	●
TREND ANALYSIS	○	◍	◍	◍	●
INTELLIGENT INTERFACE	○	○	◍	◍	●
DESIGN ASSISTANCE	○	○	○	◍	●
TRAINING ASSISTANCE	○	○	○	◍	●

HL/AIAA 9-88 (LAH)

SYSTEMS AUTONOMY PROGRAM - TECHNOLOGICAL CHALLENGES

B. WHERE WE NEED TO GO

REAL-TIME KNOWLEDGE-BASED SYSTEMS
- PARALLEL SYMBOLIC-NUMERIC PROCESSORS (100 GBYTES, 500 MIPS)
- NEURAL NETWORKS (BRAIN CELL EMULATION)
- LAYERED TRANSPARENT SW
- DIAGNOSIS AND PLANNING IN MILLISECONDS

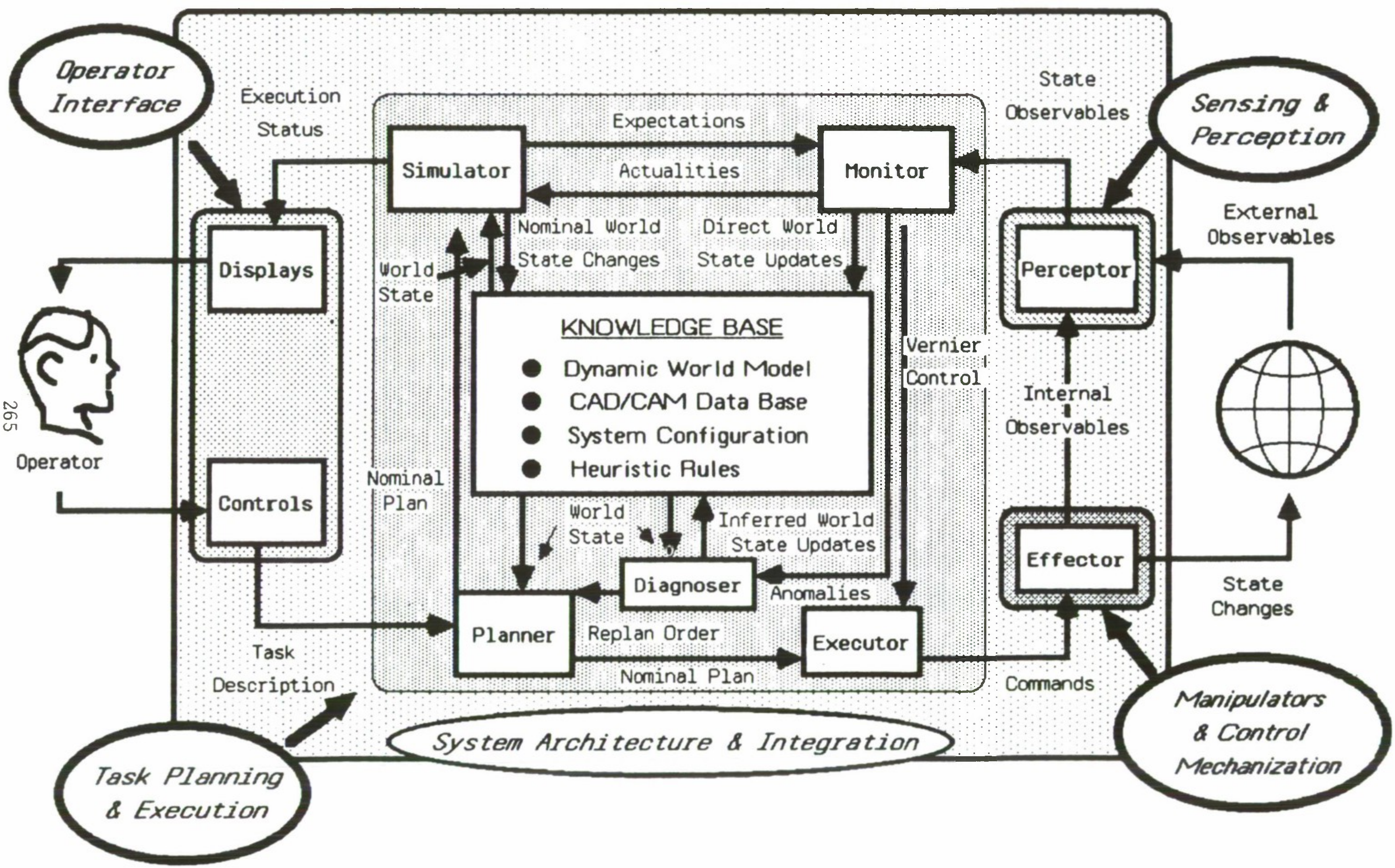
DYNAMIC KNOWLEDGE ACQUISITION & UNDERSTANDING
- AUTOMATED K-B EXPANSION IN REAL-TIME (LEARNING)
- LARGE DYNAMIC DISTRIBUTED K-B

ROBUST PLANNING AND REASONING
- COMBINED HEURISTIC RULES AND CAUSAL MODELS
- REAL-TIME CONTINGENCY REPLANNING
- DIAGNOSIS OF UNANTICIPATED FAULTS
- SPECIFIC DOMAINS ON BROAD GENERIC K-B (GRACEFUL DEGRADATION)

COOPERATING KNOWLEDGE-BASED SYSTEMS
- HIERARCHICAL AND DISTRIBUTED SYSTEMS
- HUMAN AND INTELLIGENT SYSTEMS INTERACTION

VALIDATION METHODOLOGIES
- METHODOLOGY FOR EVALUATING DECISION QUALITY
- FORMAL THEORETICAL FOUNDATION

Architecture of an Autonomous Intelligent System



SYSTEMS AUTONOMY DEMONSTRATION PROJECT

Technology Demonstration - Evolutionary Sequence

1988
Automated Control Of Single Subsystem ("Intelligent Aide")

Thermal Control System

* Monitor/real-time control of a single subsystem
* Goal and causal explanation displays
* Rule-based simulation
* Fault recognition/warning/limited diagnosis
* Resource management
* Reasoning assuming standard procedures

1990
Automated Control of Multiple Subsystems ("Intelligent Apprentice")

Thermal Control System and Power System

* Coordinated control of multiple subsystems
* Operator aids for unanticipated failures
* Model-based simulation
* Fault diagnosis for anticipated failures
* Real-time planning/replanning
* Reasoning about nonstandard procedures

1993
Hierarchical Control of Multiple Subsystems ("Intelligent Assistant")

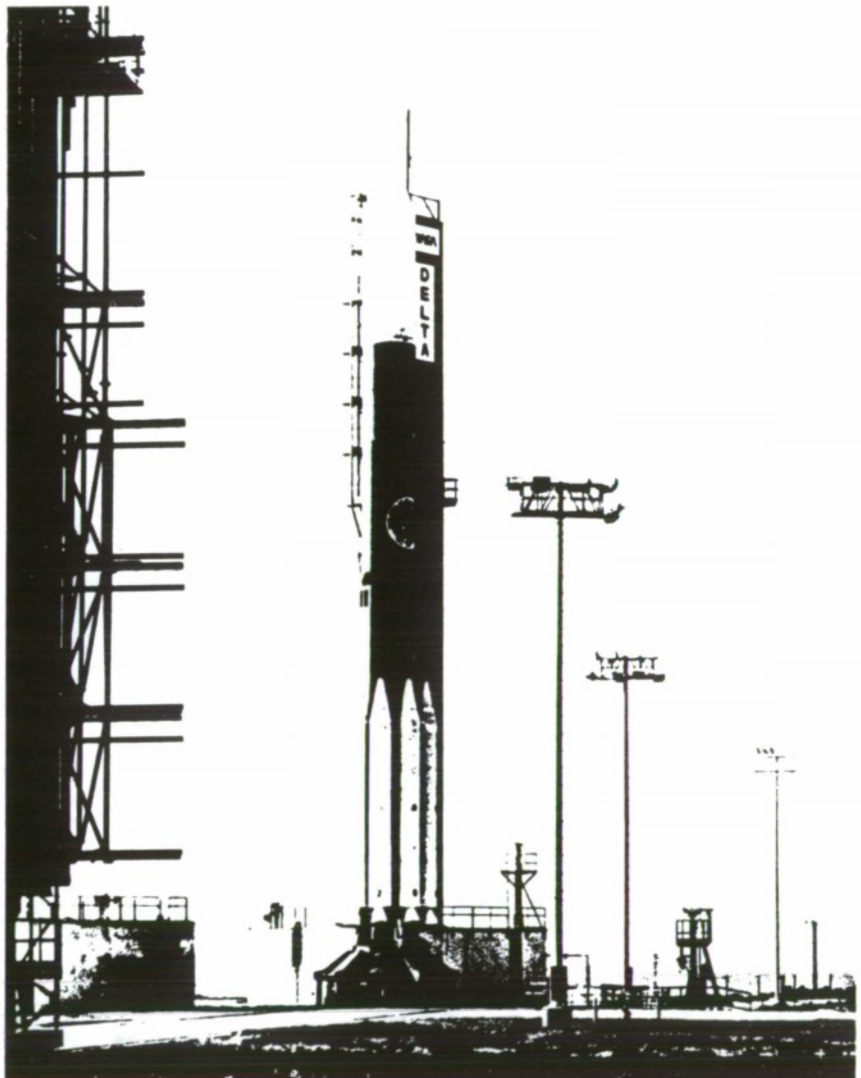
* Multiple subsystem control: ground and space
* Task-oriented dialogue & human error tolerance
* Fault recovery from unanticipated failures
* Planning under uncertainty
* Reasoning about emergency procedures

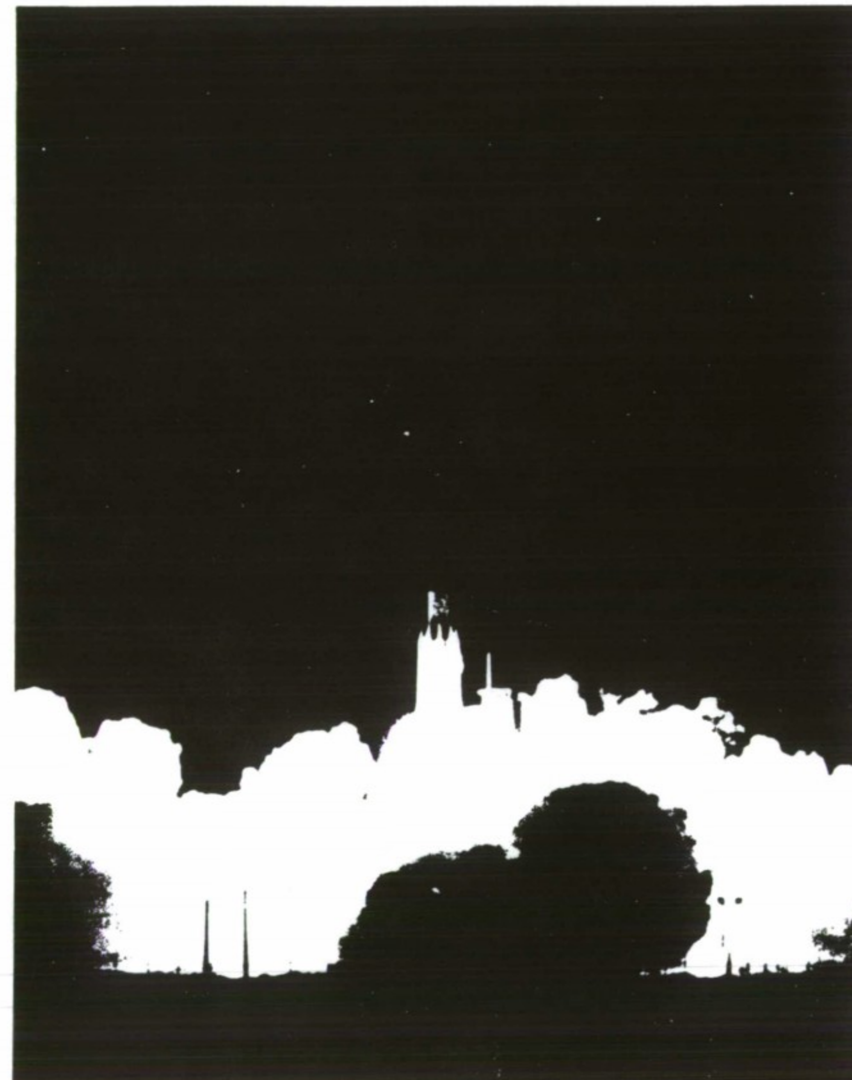
1996
Distributed Control Of Multiple Subsystems ("Intelligent Associate")

* Autonomous cooperative controllers
* Goal-driven natural language interface
* Fault prediction and trend analysis
* Automated real-time planning/replanning
* Reasoning/learning, supervision of on-board systems

HL/AIAA 9-88 (LAH)

AUTONOMOUS SYSTEMS FOR ADVANCED LAUNCH SYSTEMS (ALS)
UNMANNED LAUNCH VEHICLES

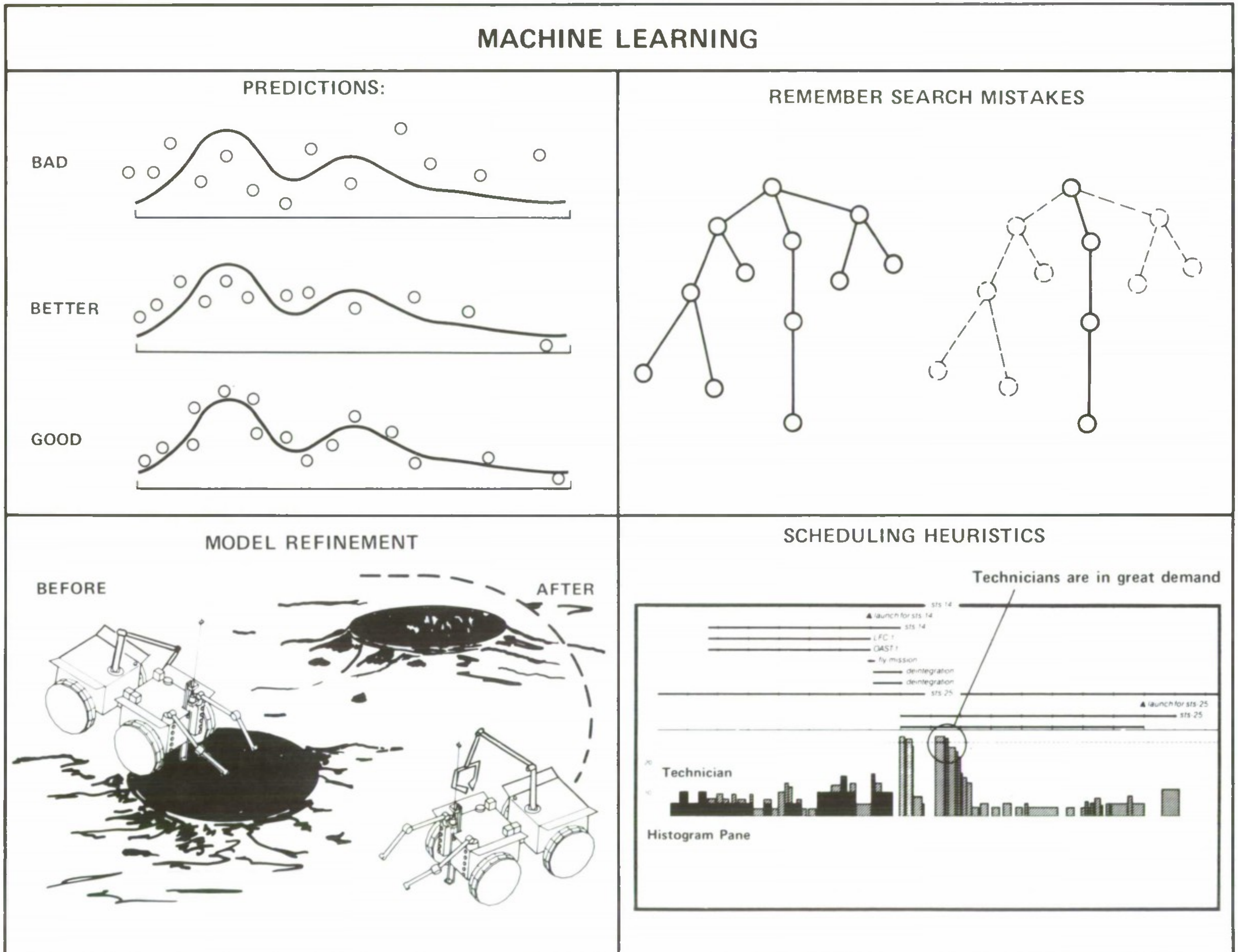


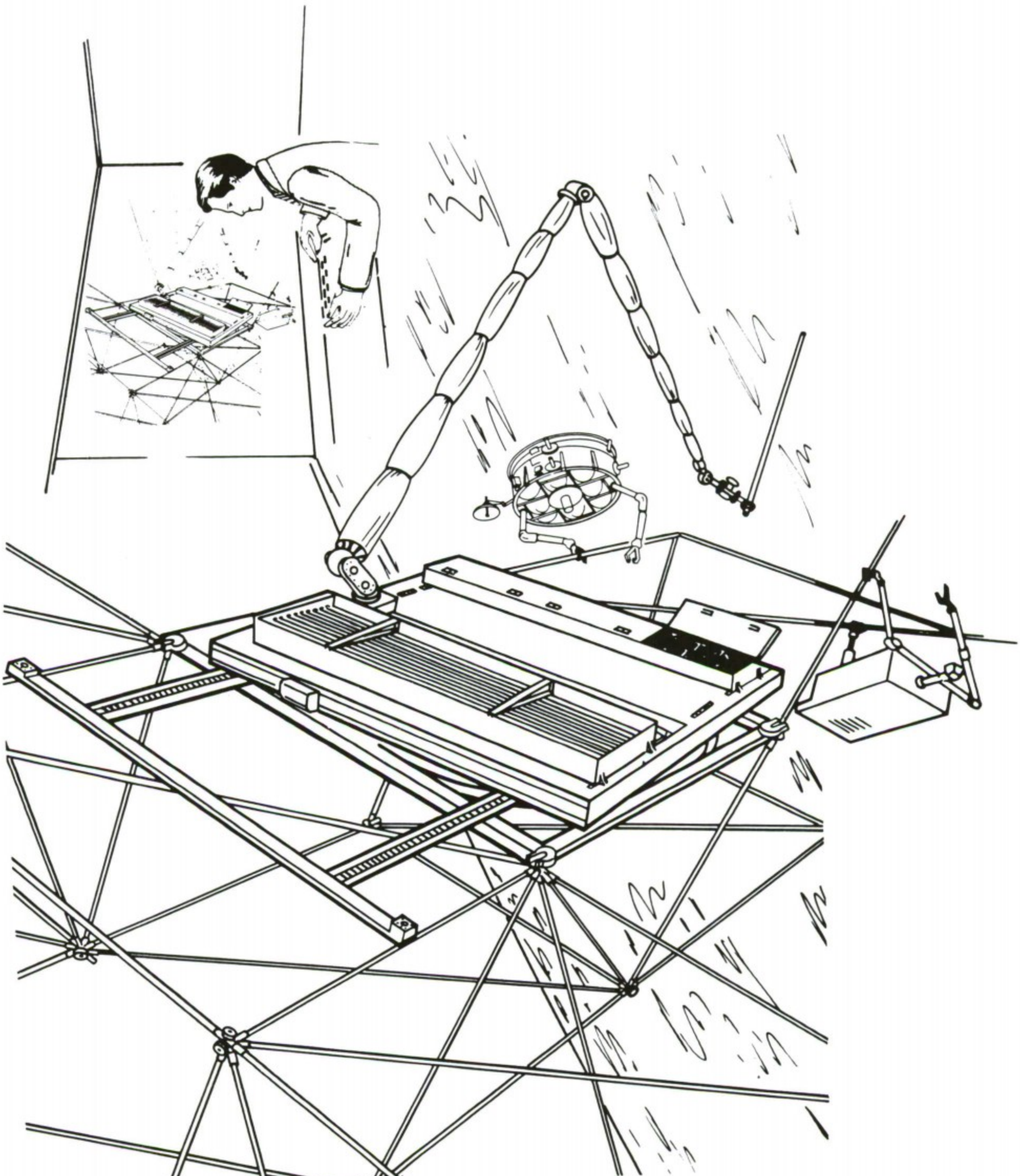


NASA AMES RESEARCH CENTER
OAST/AF-SPONSORED RESEARCH

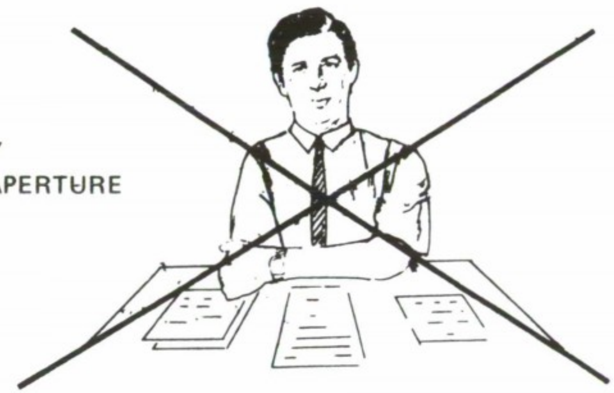
AI Research Issues

- MACHINE LEARNING
- COOPERATING KNOWLEDGE-BASED SYSTEMS
- REAL-TIME ADVANCED PLANNING AND SCHEDULING METHODOLOGIES
- MANAGEMENT OF UNCERTAINTY
- AUTOMATED DESIGN KNOWLEDGE CAPTURE
- VALIDATION OF KNOWLEDE-BASED SYSTEMS

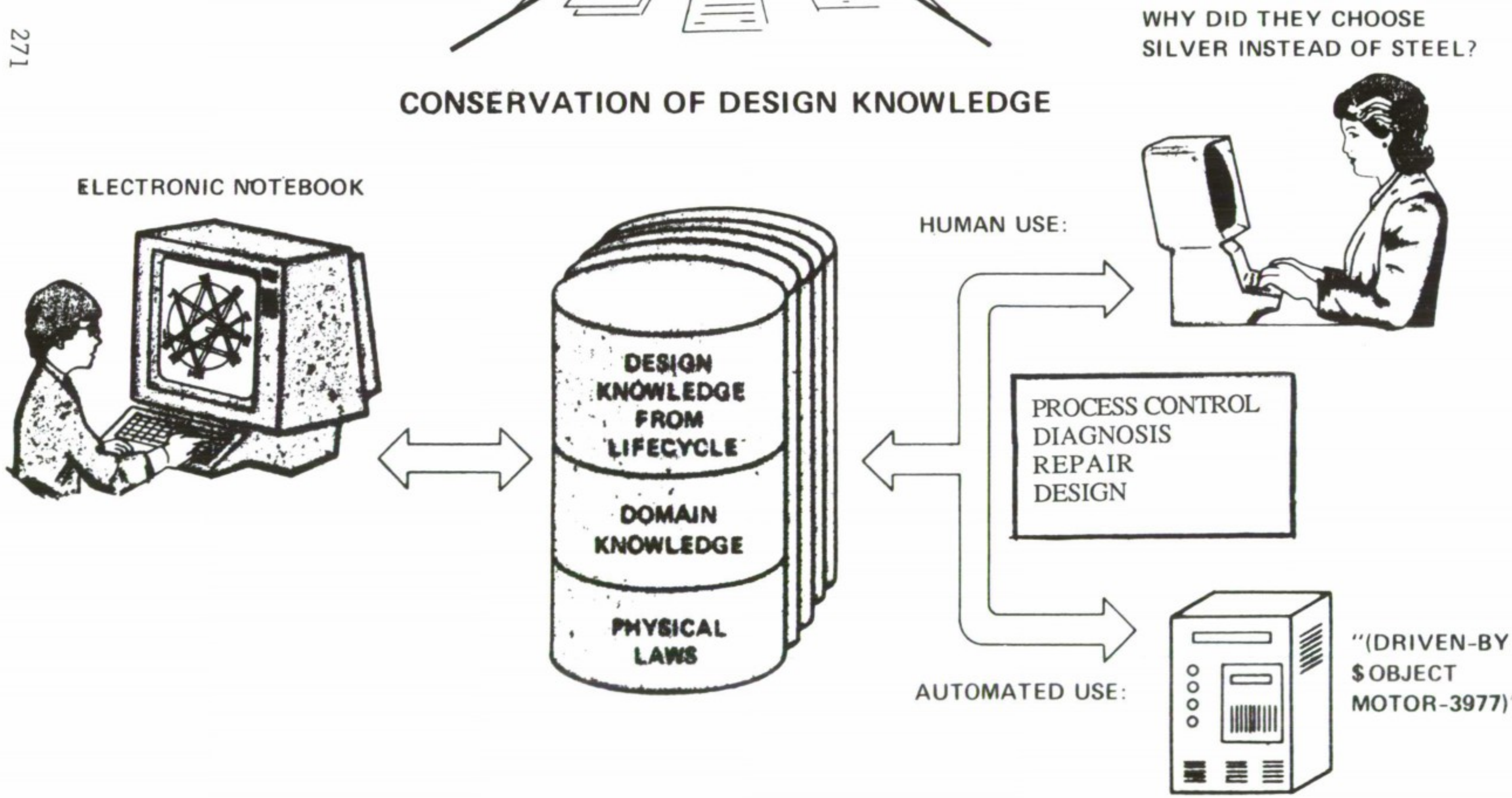

MACHINE LEARNING
PREDICTIONS:
BAD
BETTER
GOOD
REMEMBER SEARCH MISTAKES
MODEL REFINEMENT
BEFORE
AFTER
SCHEDULING HEURISTICS
Technicians are in great demand
Technician
Histogram Pane

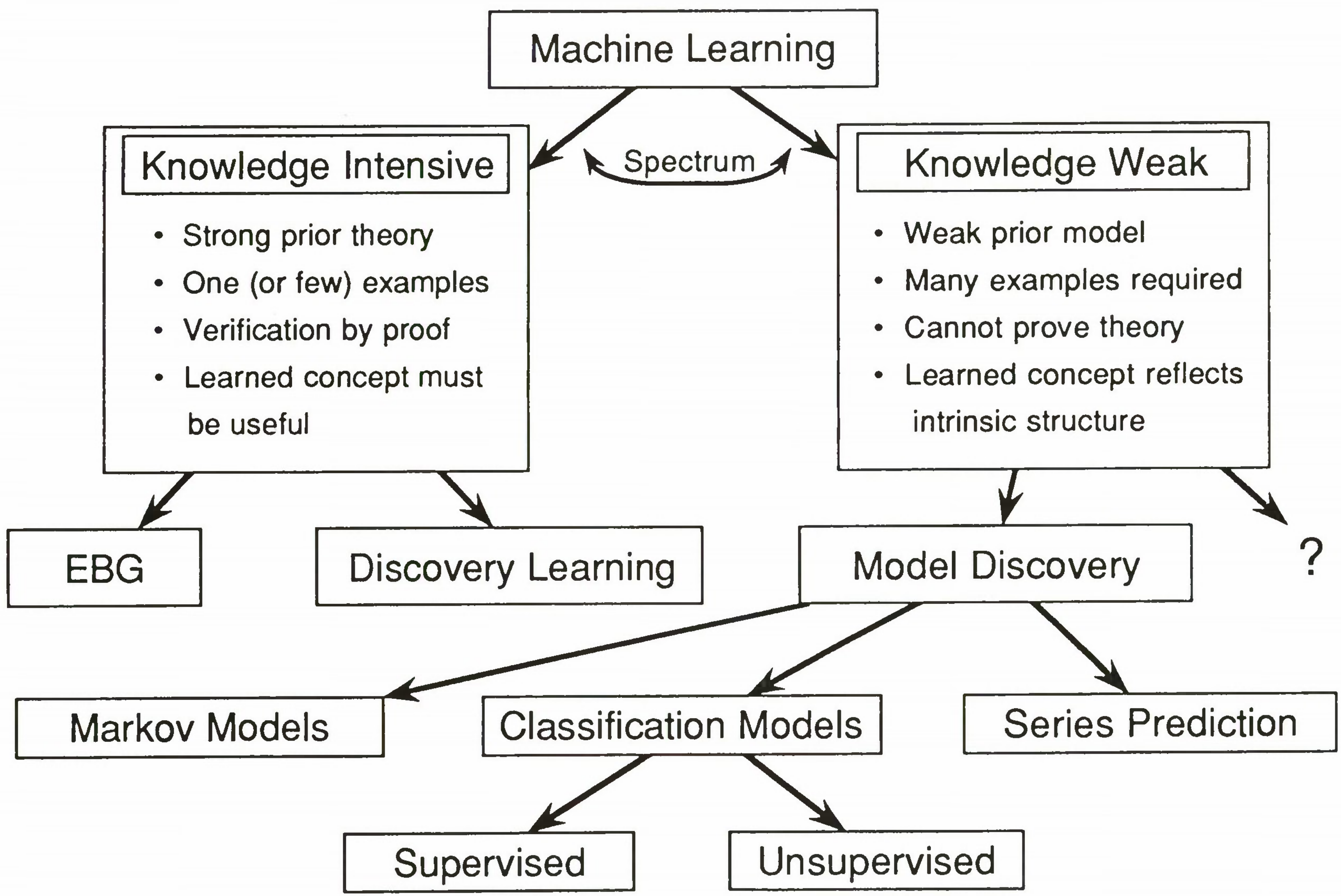


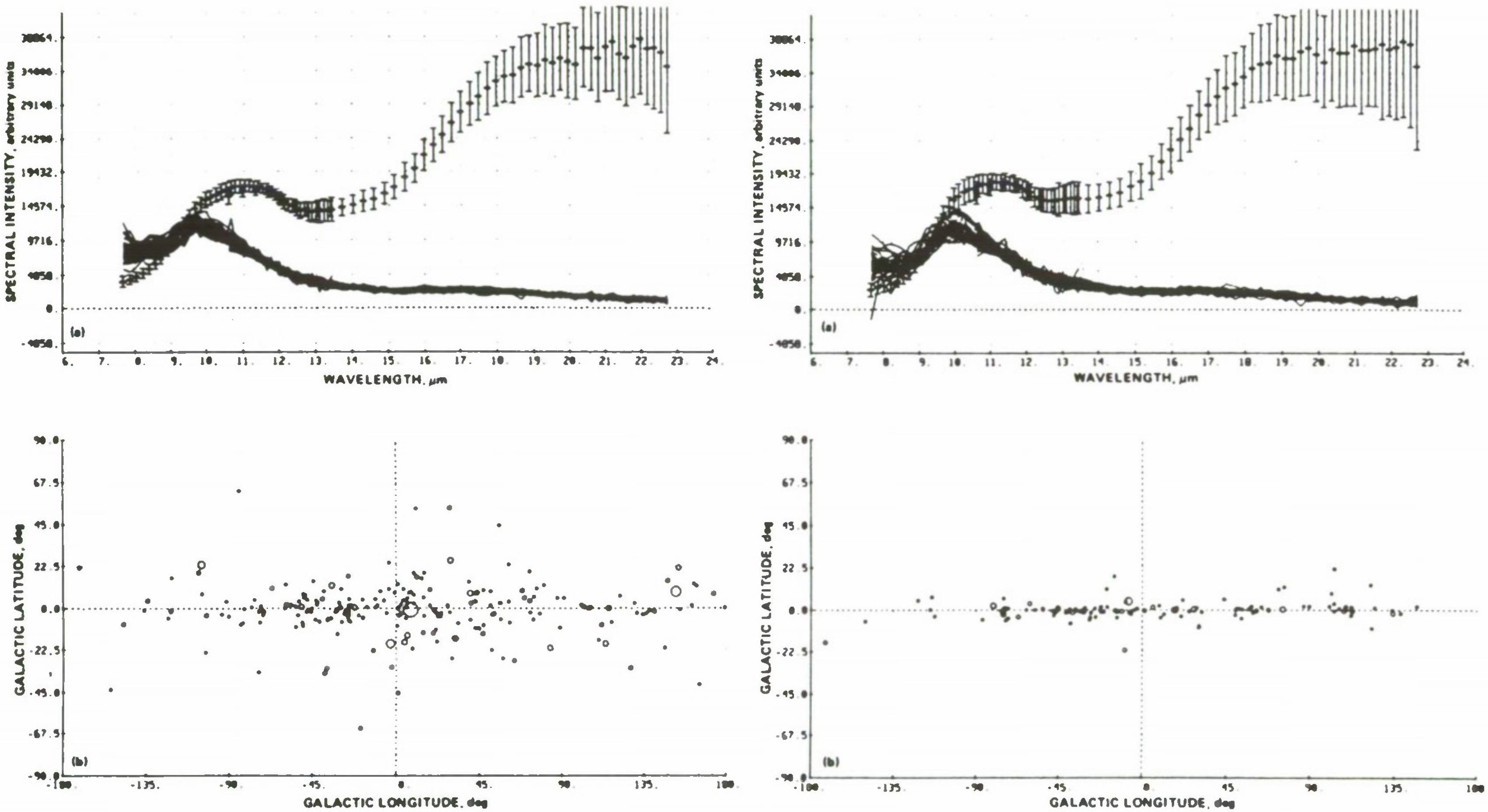
DESIGN KNOWLEDGE LOST WHEN DESIGNER LEAVES:



CONSERVATION OF DESIGN KNOWLEDGE



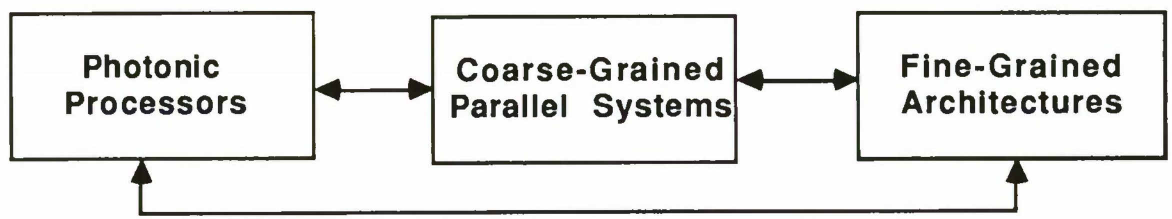

Machine Learning
Spectrum
Knowledge Intensive
• Strong prior theory
• One (or few) examples
• Verification by proof
• Learned concept must be useful
Knowledge Weak
• Weak prior model
• Many examples required
• Cannot prove theory
• Learned concept reflects intrinsic structure
EBG
Discovery Learning
Model Discovery
?
Markov Models
Classification Models
Series Prediction
Supervised
Unsupervised



The spectra show two closely related IRAS classes with peaks at 9.7 and 10.0 microns. This discrimination was achieved by considering all channels of each spectrum. AutoClass currently has no model of spectral continuity. The same results would be found if the channels were randomly reordered.

The galactic location data, not used in the classification, tends to confirm that the classification represents real differences in the sources.

Evolution of Advanced Architectures for Real-time, On-board Teraflop Systems



	Photonic Processors	Coarse-Grained Parallel Systems	Fine-Grained Architectures
Function	RT Image Processing	Knowledge Understanding & Control	Deep Reasoning
Technology Status	Applied R&D	Development	Basic Research
Technology Forecast	Late 1990s	Current	Early 2000s
Examples	KBS-controlled Photonic Processor	SVMS (6-Processor System)	Neural Networks Fuzzy Logic Computes and Controllers

HL/AIAA 9-88 (LAH)

Computer Architecture Research Issues (Numeric/Symbolic Multiprocessor Systems)

- OPERATING SYSTEMS FOR REAL-TIME MULTIPROCESSING SYSTEMS IN A HETEROGENEOUS ENVIRONMENT
- VALIDATED COMPILERS AND TRANSLATORS FOR AN ADA-BASED MULTIPROCESSING ENVIRONMENT
- DATABASE MANAGEMENT FOR LARGE DISTRIBUTED DATABASES GREATER THAN 10GB
- AUTOMATED LOAD SCHEDULING FOR MULTIPROCESSORS
- REAL-TIME FAULT TOLERANCE AND RECONFIGURATION
- RADIATION HARDNESS WITH MINIMUM PERFORMANCE COMPROMISES
  - PROCESS TECHNOLOGY
  - VLSI/VHSIC TRADEOFFS
  - EFFICIENT COMPILERS AND INSTRUCTION SET ARCHITECTURES

SPACEBORNE VHSIC MULTIPROCESSOR SYSTEM (SVMS)
NASA/AF/DARPA COLLABORATION

PROCESS

VHSIC TECHNOLOGY

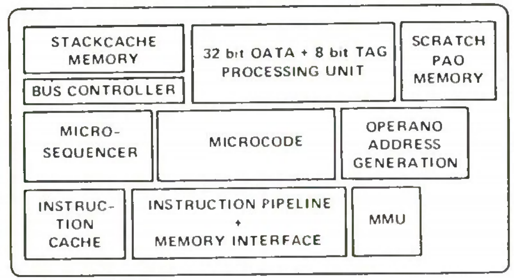
0.5μ TARGET
1.25μ BACKUP

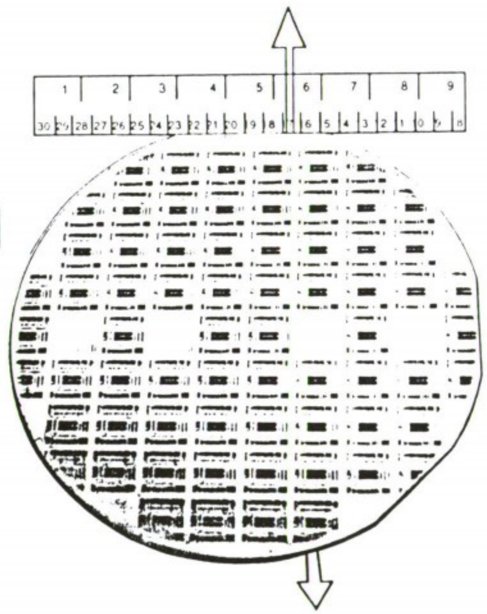
RAD-HARD CMOS

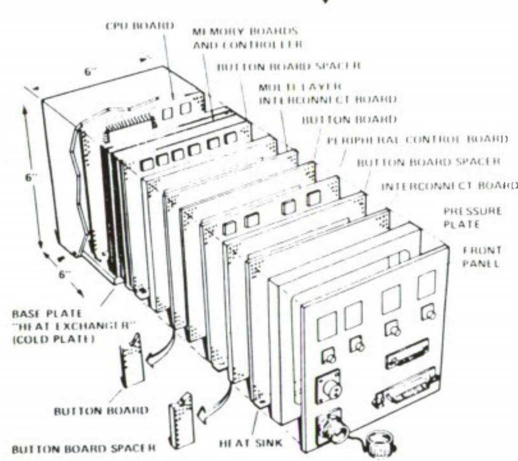
10^5 RADS RADIATION RESISTANCE
NO SINGLE EVENT UPSETS

SYSTEM CHARACTERISTICS

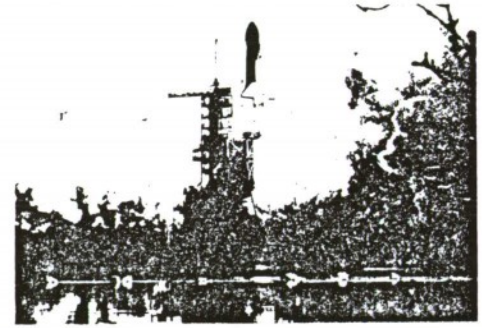
- PARALLEL ARCHITECTURE
  - 40-BIT SYMBOLIC PROCESSORS
  - 32-BIT NUMERIC PROCESSORS
- FAULT-TOLERANCE/AUTOMATED RECONFIGURATION
- OPTICAL INTERCONNECTS
- 25 MIPS SUSTAINED UNIPROCESSOR PERFORMANCE (40 MIPS TARGET)
  - MINIMUM OF 100 MIPS OVERALL SYSTEM PERFORMANCE
- DBMS FOR 10G BYTE MEMORY MANAGEMENT

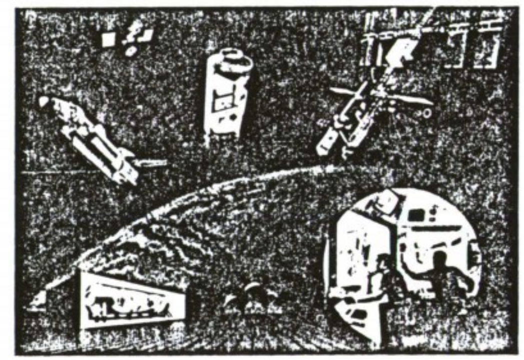


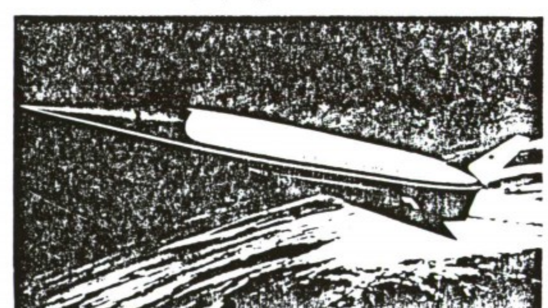




POTENTIAL SPACE
&
AERONAUTICS APPLICATIONS







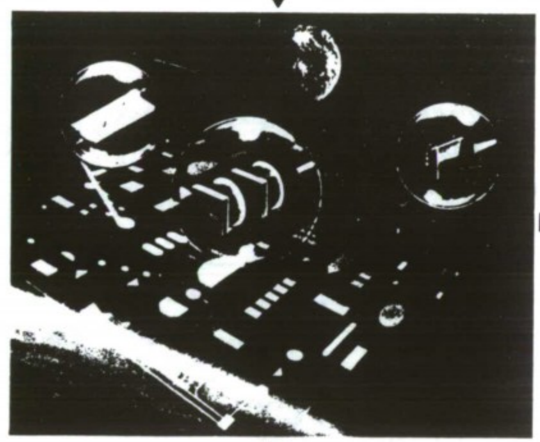
PHOTONIC PROCESSOR FOR REAL-TIME IMAGE UNDERSTANDING

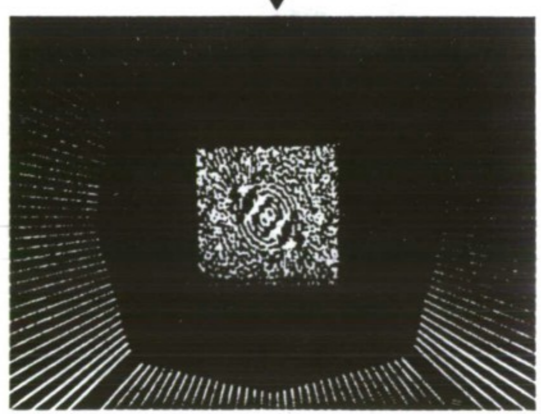
OBJECTIVES

- **REAL-TIME PHOTONIC PROCESSORS & TECHNIQUES**
  for Terrain Analysis Tasks
- **SYSTEM CONTROL & INTEGRATION OF EMBEDDED PHOTONIC PROCESSORS**
  with Integrated Numeric/Symbolic Multiprocessor Systems
- **TECHNOLOGY FEASIBILITY DEMONSTRATIONS**
  Focused on Planetary Rovers & Space Vehicles

BENEFITS

- Real-time, High Performance Parallel Processing for Image Processing & Understanding
- Fault Tolerance
- Low Power, Weight, and Size





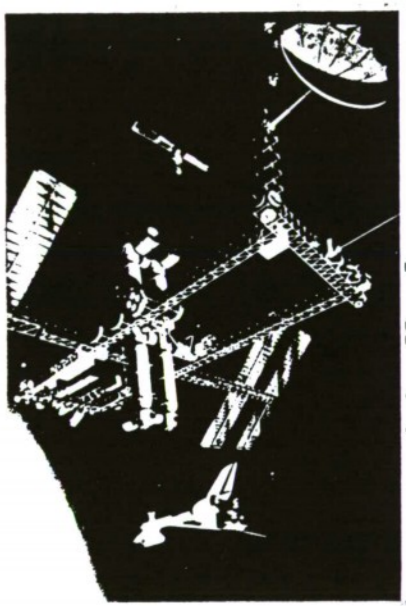
POTENTIAL APPLICATIONS

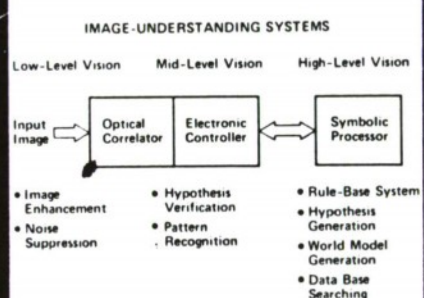

Autonomous Landing


Sample Acquisition and Analysis


Sample Return

NASA AMES RESEARCH CENTER
OAST-SPONSORED RESEARCH





Knowledge-Based Systems

The tasks involved with an image-understanding-system can be divided into three layers as shown. The problem is to find a synergistic balance between all layers so that as knowledge of the image accrues, the reliability of the interpretation, recognition, and enhancement increases, while the amount of required computation decreases. Methodologies of organizing a knowledge-base of object and using a rule-based system to effectively search the knowledge-base and directing the computations of photonic processors are being developed. The majority of the domain specific knowledge for a task will reside in the interpretative level making the photonic processor a general purpose computing tool.

Neural Networks

NASA
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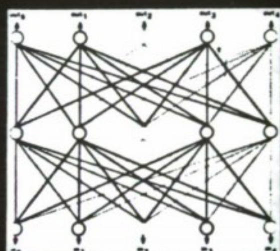
Backward-Error Propagation

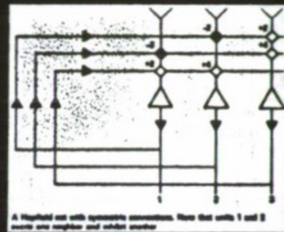


RUMMELHART

There are many models in the real world that cannot be represented in a two-layer system such as the Hopfield model. For example, there exist no values that can be assigned to connection strengths to yield to appropriate outputs for the exclusive-or (XOR) function. The solution is to introduce a third layer, called the hidden layer, between the input and output layers. This hidden layer creates the ability to incorporate an internal representation that facilitates difficult mappings between the two external layers.

INFORMATION SCIENCES DIVISION

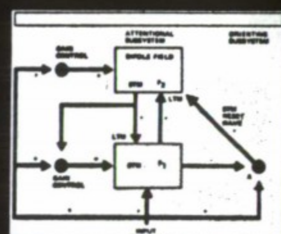
Hopfield



HOPFIELD

J.J. Hopfield demonstrated the formal analogy between a net of neuron-like elements with symmetric connections, called a "Hopfield Net", and a material called a spin-glass, which consists of a random mixture of both ferromagnetically and anti-ferromagnetically interacting spins, exhibiting no net magnetism. Each element of a Hopfield net must both excite and inhibit its neighbors.

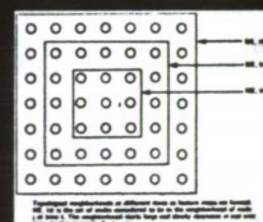
Adaptive Resonance Theory



GROSSBERG

Carpenter and Grossberg, in the development of their Adaptive Resonance Theory, have designed a net which forms clusters and is trained without supervision. The leader algorithm selects the first input as the exemplar in the first cluster. The next input is compared to the first input exemplar. It "follows the leader" and is clustered with the first if the distance of the first is less than a threshold. Otherwise it is the exemplar for the new cluster. This process is repeated for all following inputs.

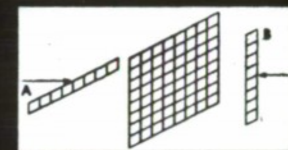
Self-Organizing Maps



KOHONEN

One important organizing principle of sensory pathways in the brain is that the placement of neurons is orderly and often reflects some physical characteristic of the external stimulus being sensed. For example, at each level of the auditory pathway, nerve cells and fibers are arranged anatomically in relation to the frequency which elicits the greatest response in each neuron. Kohonen presents one such algorithm which produces what he calls self-organizing feature maps similar to those that occur in the brain.

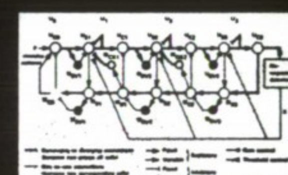
Bidirectional Associative Memory



KOSKO

A bidirectional associative memory (BAM) is a two-layer nonlinear feedback network that behaves as a heteroassociative content addressable memory. M stimulus-response associations (A_i, B_i) are stored by a BAM by summing bipolar correlation matrices. They are recalled as fixed points of the BAM dynamical system.

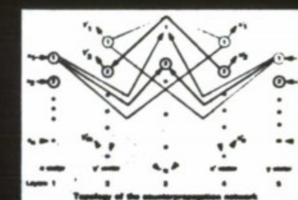
Neocognitron



FUKUSHIMA

The model is a hierarchical multilayered network consisting of a cascade of many layers of simplified neural cells. It has backward as well as forward connections between cells in adjoining layers. The forward signal manages the function of pattern recognition, while the backward signal manages the function of selective attention and associative recall. The forward and backward signals interact with each other at every stage of the hierarchical network.

Counter Propagation

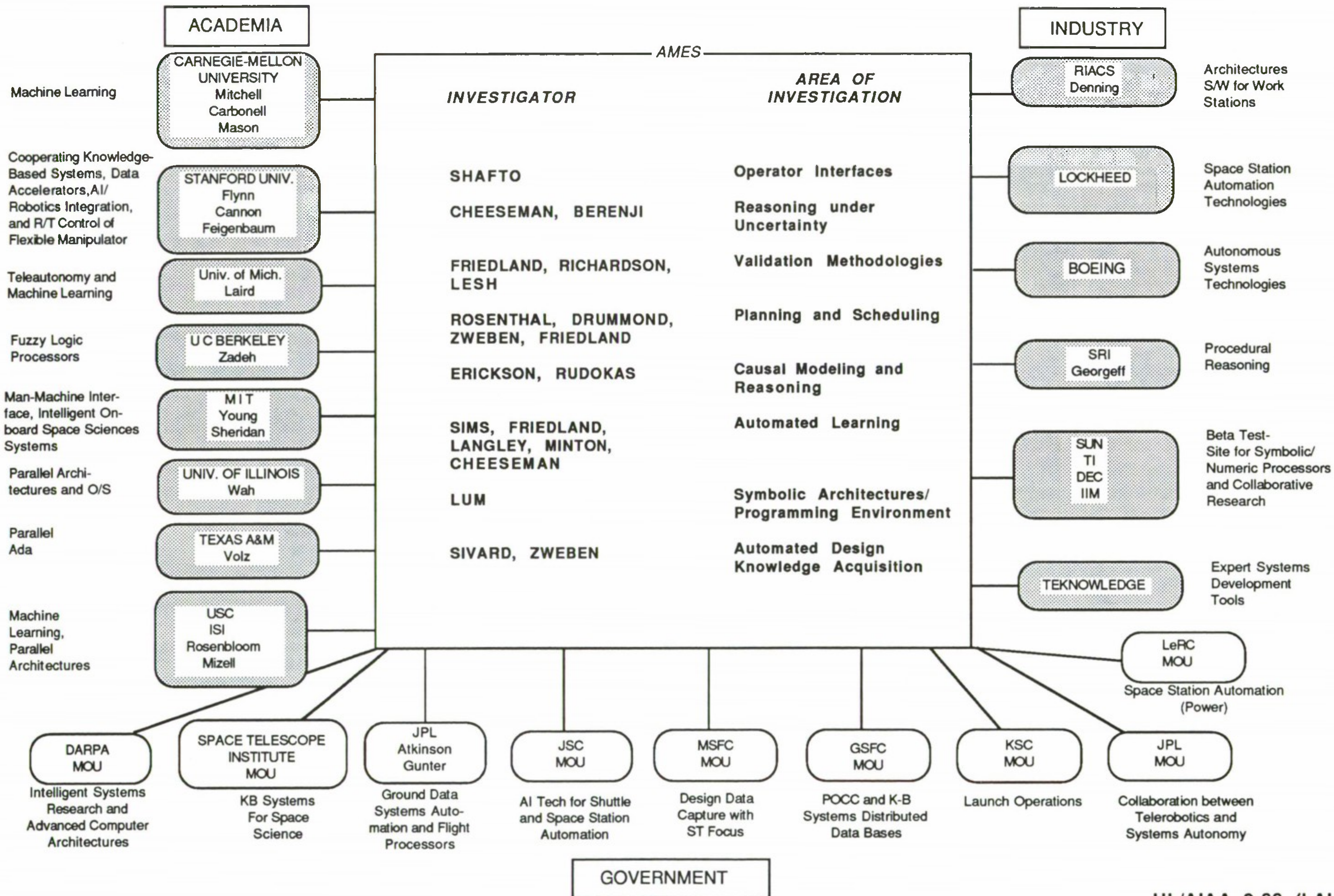


HECHT-NIELSEN

The counterpropagation network (CPN) will self-organize a near-optimal lookup table approximation to the mapping used to generate its data. The method works equally well for both binary and continuous vector mappings. It is shown that for a sufficiently large network the mapping approximation can be made essentially as accurate as desired. The counterpropagation network architecture is a combination of a portion of the self-organizing map of Kohonen and the outstar structure of Grossberg.

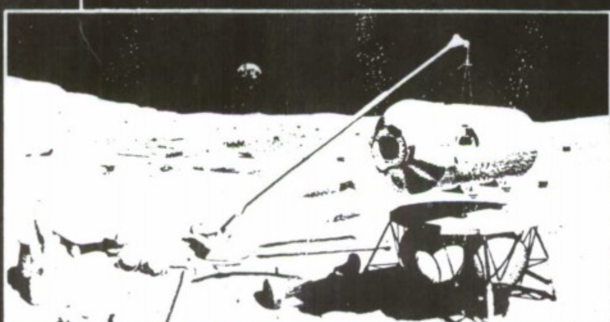
Ames Research Center

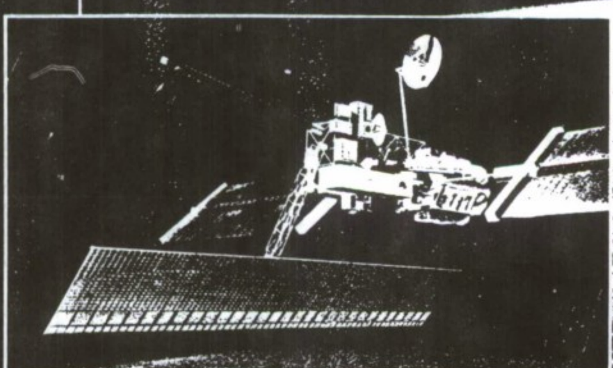
COLLABORATIVE AI AND COMPUTER ARCHITECTURES RESEARCH TEAM



HL/AIAA 9-88 (LAH)

America's Future in Space





SENSORS RESEARCH AND TECHNOLOGY

James A. Cutts

TECHNOLOGY FOR FUTURE NASA MISSIONS

AN AIAA/OAST CONFERENCE
ON CSTI AND PATHFINDER

12 - 13 SEPTEMBER, 1988

WASHINGTON D.C.

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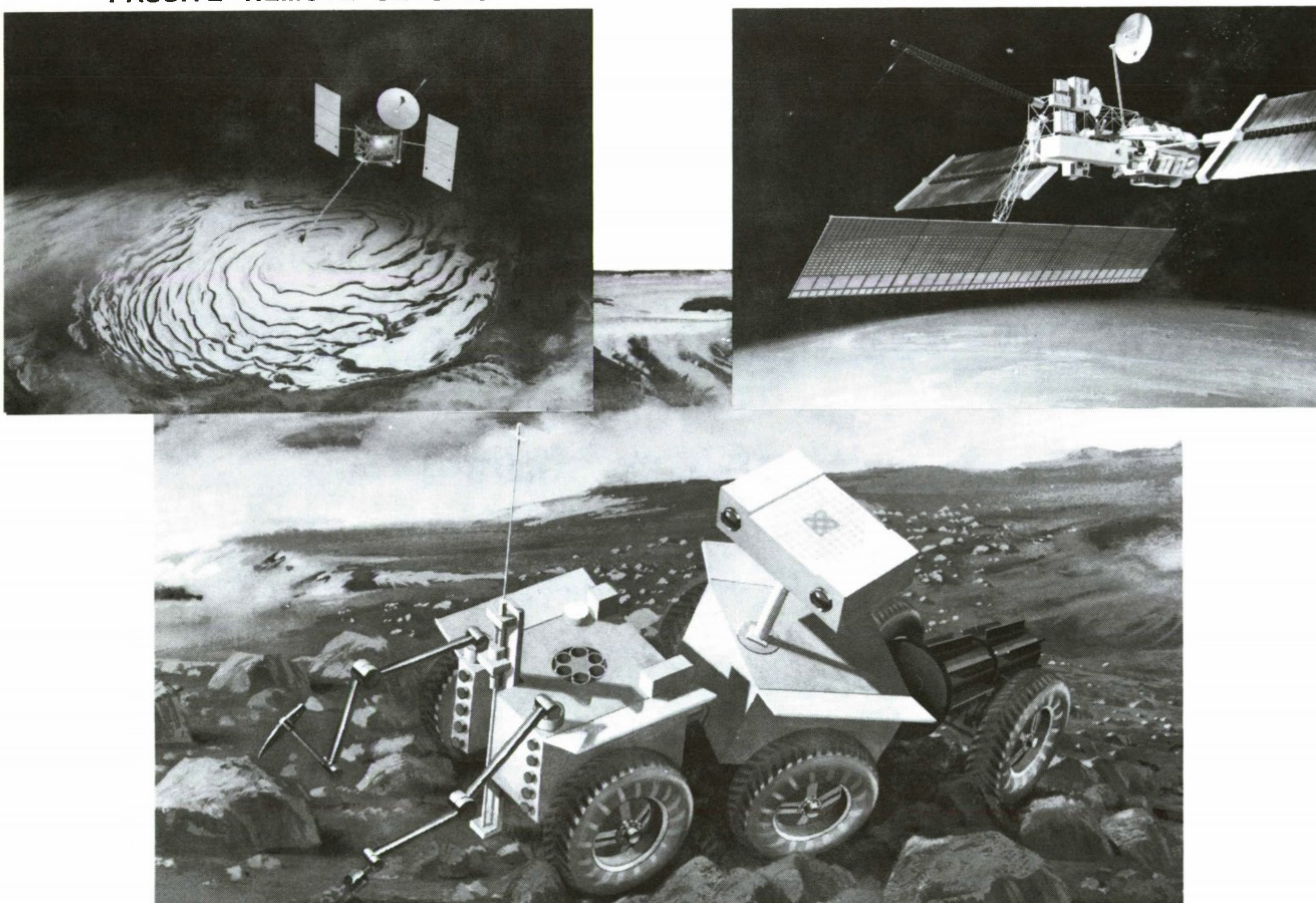
SENSING TECHNIQUES FOR SPACE SCIENCE

PASSIVE REMOTE SENSING

ACTIVE REMOTE SENSING



IN-SITU SENSING

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SENSOR RESEARCH AND TECHNOLOGY
GOALS AND APPROACH

- DEVELOP ENABLING AND ENHANCING SENSOR TECHNOLOGY FOR NASA SPACE SCIENCE MISSIONS

- EMPHASIZE DEVICE AND COMPONENT TECHNOLOGIES WITH MEDIUM-TERM AND LONG RANGE IMPACT

- PROGRAM ELEMENTS ARE
    - PASSIVE REMOTE SENSING TECHNOLOGY
        - ⇨ COHERENT (HETERODYNE) SENSING
        - ⇨ NON-COHERENT (DIRECT) SENSING
    - ACTIVE SENSING
    - SPACE COOLER TECHNOLOGY

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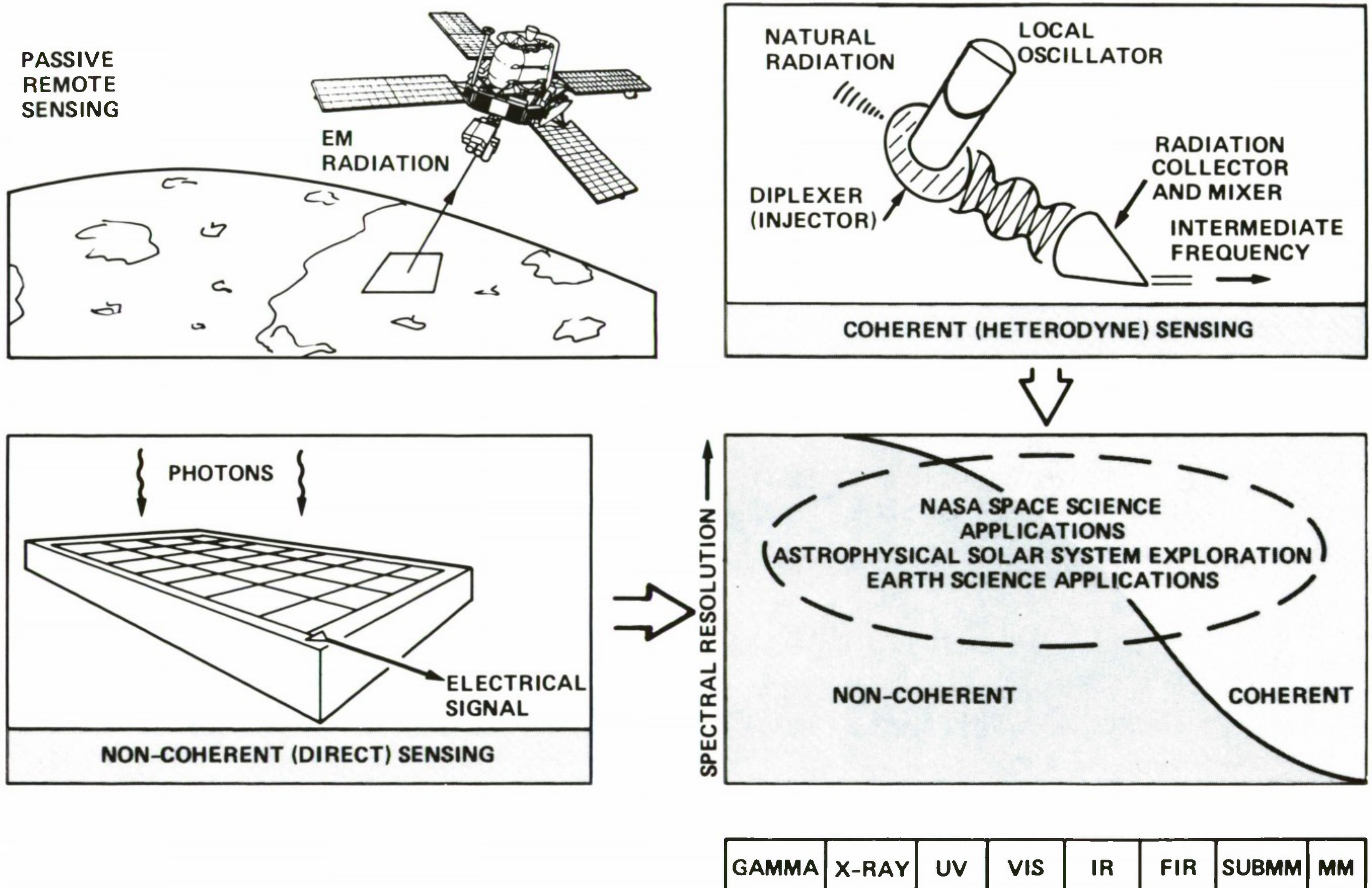
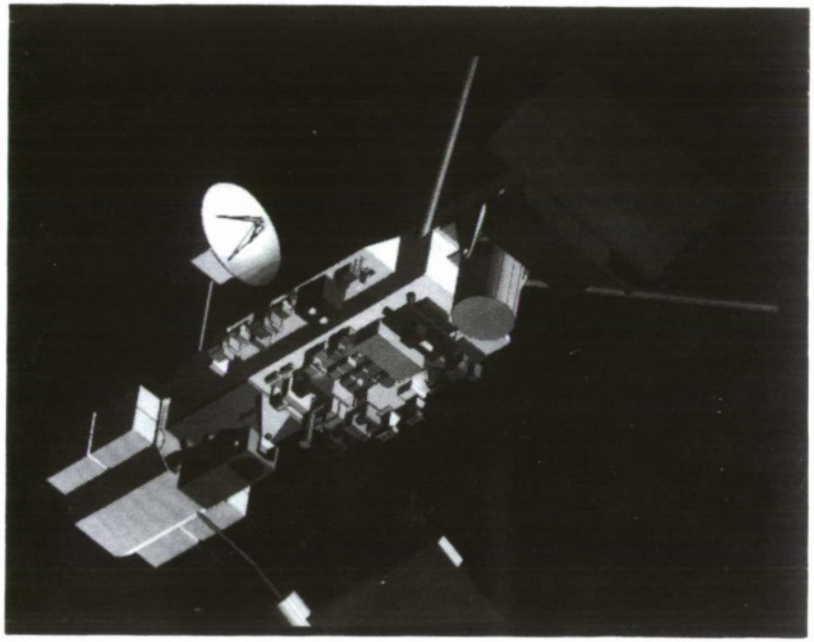
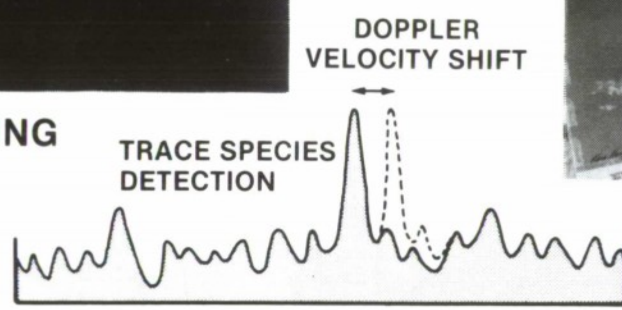
PASSIVE REMOTE SENSING: TECHNIQUES AND APPLICATIONS



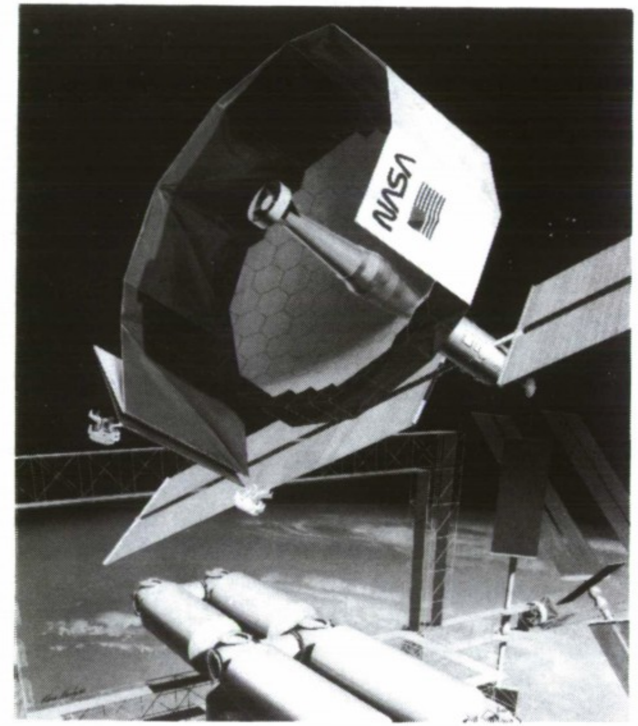
NASA SUBMILLIMETER COHERENT SENSING



EARTH OBSERVING SYSTEM



HIGH RESOLUTION SPECTRUM



LARGE DEPLOYABLE REFLECTOR

APPLICATIONS

- MEASURE TRACE SPECIES IN ATMOSPHERES OF EARTH AND PLANETS AND ASTROPHYSICAL GASES AND PLASMAS
- MAP DISTRIBUTIONS OF TEMPERATURES AND VELOCITIES

COHERENT SENSOR RESEARCH
SUBMILLIMETER MIXERS

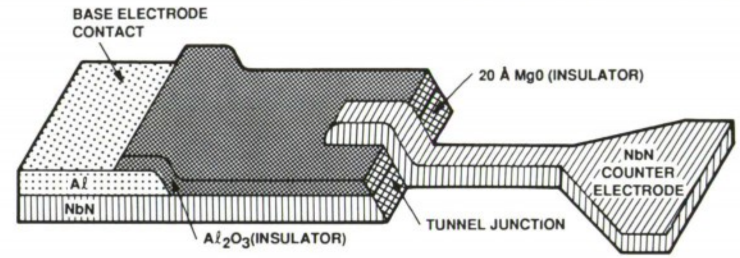
REQUIREMENTS

- QUANTUM EFFICIENCY
  > 10%, 300 - 3000 GHz
- RUGGED PLANAR TECHNOLOGY SUITED TO ARRAYS
- LOW LOCAL OSCILLATOR POWER

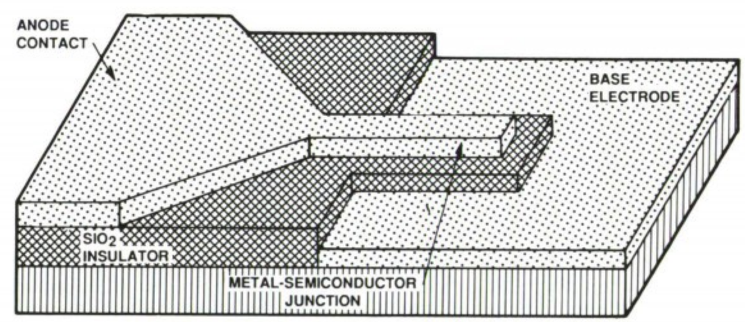
APPROACH

- DEVELOP THREE TECHNOLOGIES TO COVER SUBMILLIMETER SPECTRAL RANGE AND SUITABLE FOR DIFFERENT OPERATING TEMPERATURES

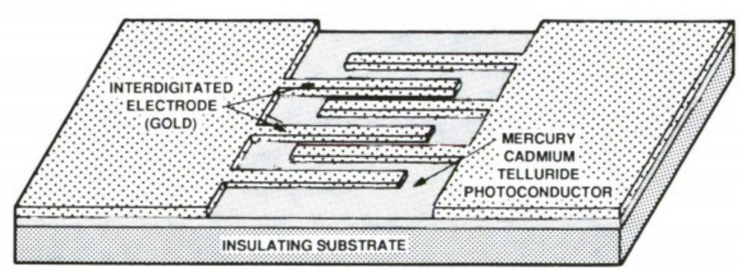
SIS TUNNEL JUNCTION



SCHOTTKY BARRIER DIODE IN Ga As



INTERDIGITATED ELECTRODE PHOTOCONDUCTIVE MIXER



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COHERENT SENSOR RESEARCH

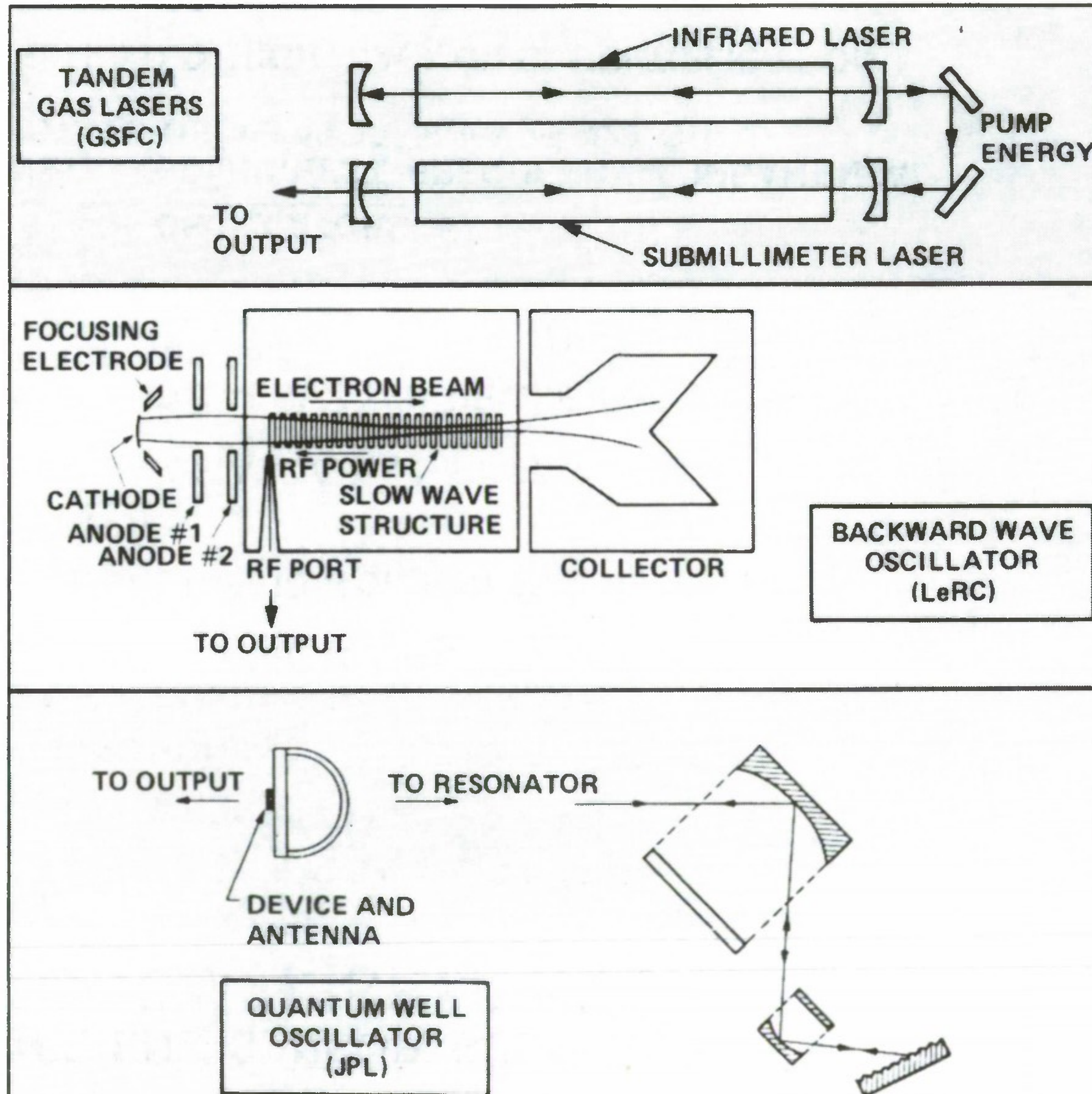
SUBMILLIMETER LOCAL OSCILLATOR SOURCES

REQUIREMENTS

- LOW POWER AND MASS
- COMPACT AND RUGGED
- TUNEABLE 300-3000 GHz
- SPECTRALLY PURE WITH 1μ W - 1mW OUTPUT

APPROACH

- DEVELOP THREE TECHNOLOGIES TO PROOF-OF-CONCEPT
- SELECT TECHNOLOGY FOR SPACE QUALIFIABLE PROTOTYPE IN 1988



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COHERENT SENSOR RESEARCH
ACCOMPLISHMENTS

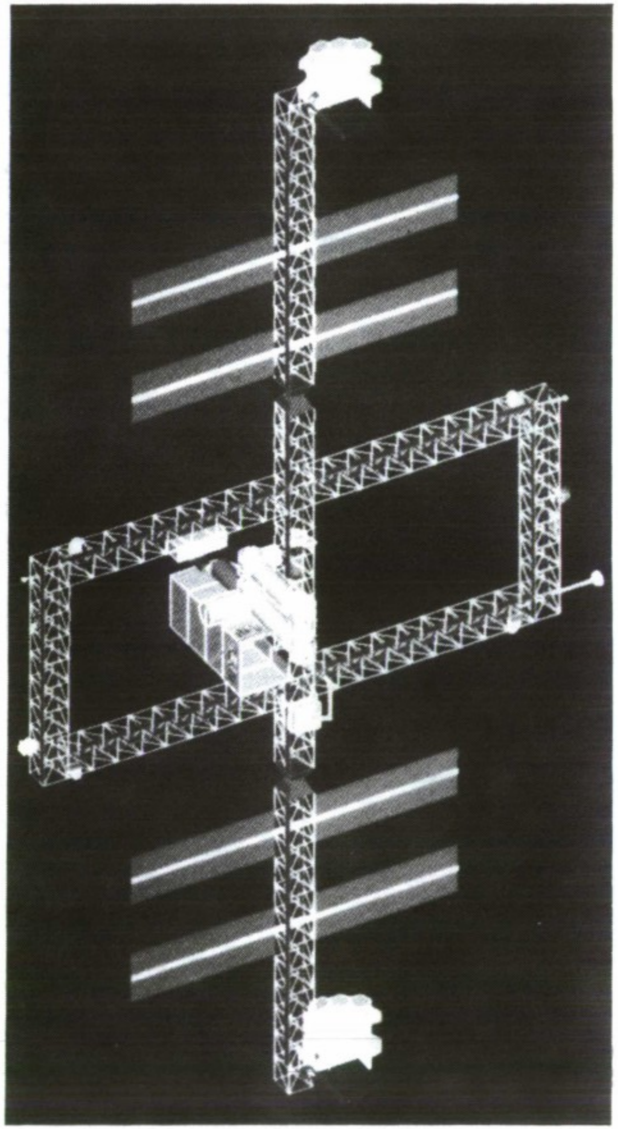
MIXERS

- SIS TUNNEL JUNCTIONS
  - HIGHEST FREQUENCY EVER REPORTED IN LEAD JUNCTIONS (600 GHz) - FY 86
  - FIRST DEMONSTRATION OF NbN MIXER - FY 88
- IDEPC/MCT DEVICES
  - ACHIEVED 2% QE AT 10 Thz - FY 87
  - DESIGNED AND FABRICATED DEVICE FOR 3 THz OPERATION - FY 88

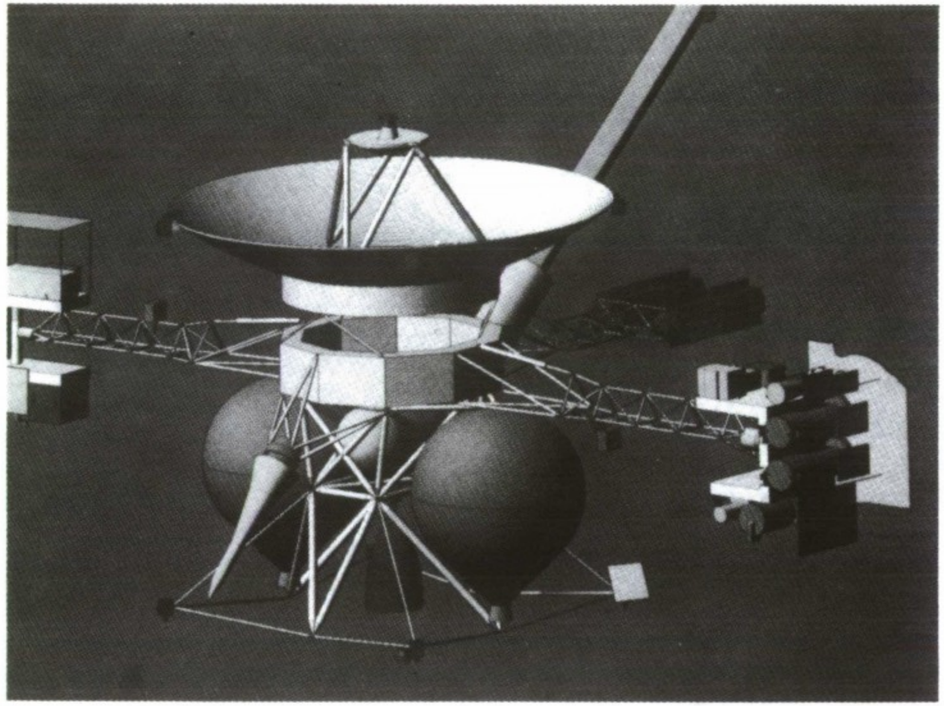
LOCAL OSCILLATORS

- ALL SOLID STATE OSCILLATORS
  - DEMONSTRATED HIGHEST FREQUENCY FUNDAMENTAL SOLID STATE OSCILLATOR (6 μW @ 420 GHz)
  - DEMONSTRATED HIGH HARMONIC MULTIPLICATION
- BACKWARD WAVE OSCILLATOR
  - FIRST DEMONSTRATION OF OSCILLATION AT 200 GHz

NON-COHERENT SENSORS



SPACE STATION



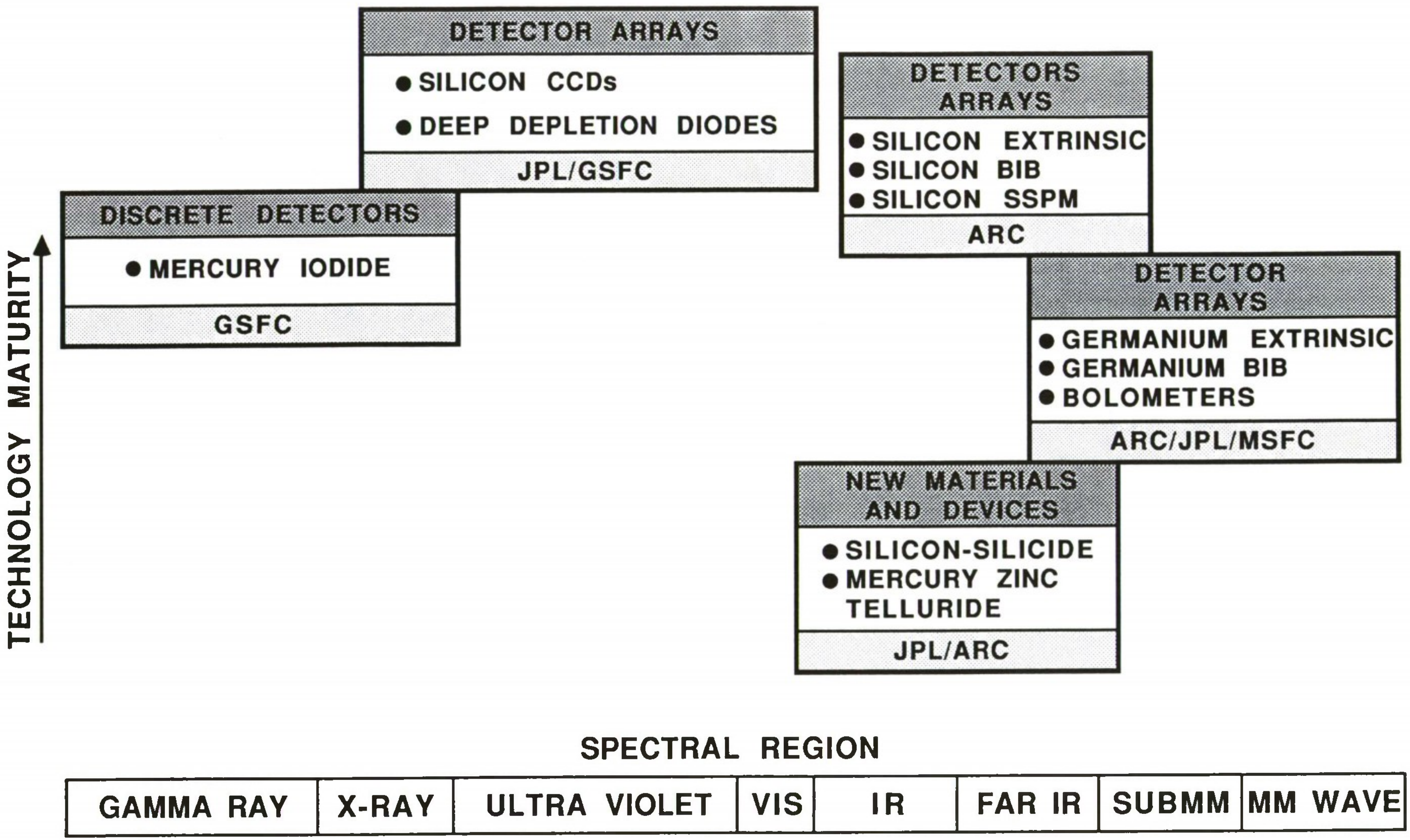
MARINER MARK-II SPACECRAFT

APPLICATIONS

- MULTISPECTRAL IMAGING OF THE SURFACES OF EARTH AND PLANETS
- MOISTURE AND TEMPERATURE SOUNDING OF ATMOSPHERES
- IMAGING AND SPECTROSCOPY OF ASTROPHYSICAL OBJECTS

NON-COHERENT SENSORS

KEY TECHNOLOGIES



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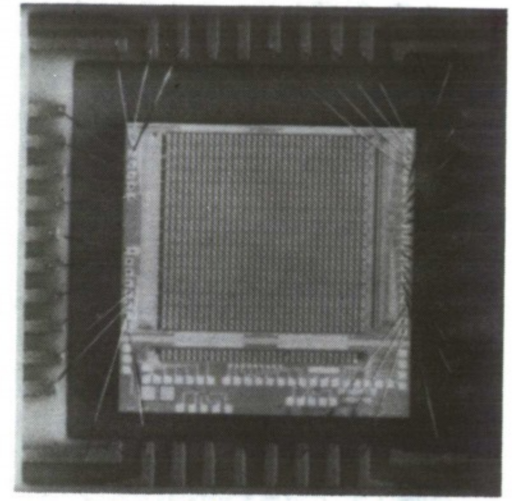
NON-COHERENT SENSORS
INFRARED TO MILLIMETER WAVE TECHNOLOGY

REQUIREMENTS

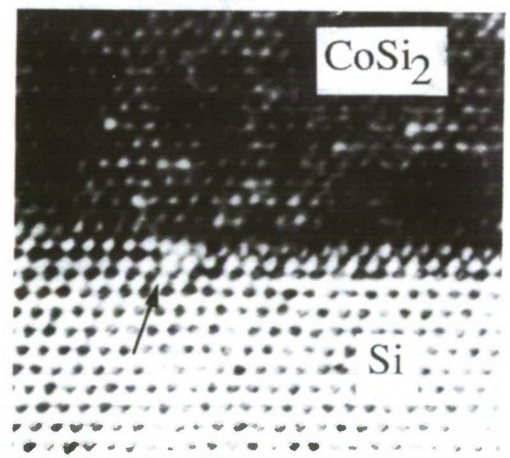
- DIVERGENT REQUIREMENTS DEPENDING ON
  - ⇒ SPECTRAL REGION
  - ⇒ SPECTRAL APPLICATION

APPROACH

- ADAPT MATURING DoD-SPONSORED EXTRINSIC-SILICON TECHNOLOGY TO MEET NASA NEEDS FOR FAR IR
- DEVELOP NEW GERMANIUM-BASED TECHNOLOGY FOR SUBMILLIMETER
- DEVELOP ENABLING MATERIALS AND DEVICE TECHNOLOGIES TO MEET LONG RANGE NEEDS FOR LARGE ARRAYS AND HIGHER TEMPERATURE OPERATION



32 x 32 DETECTOR AND MULTIPLEXER



ULTRA HIGH MAGNIFICATION VIEW OF CROSS SECTION OF SILICON-COBALT SILICIDE DETECTOR MATERIAL

NASA

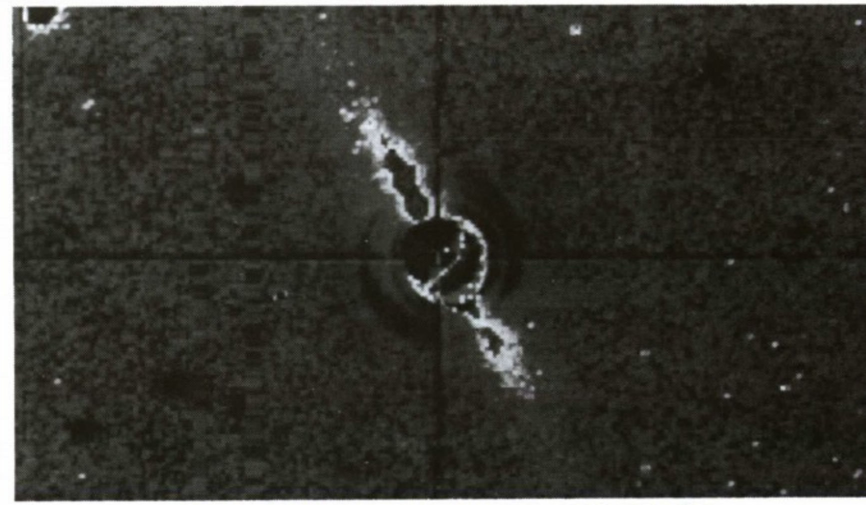
NON-COHERENT SENSORS
GAMMA RAY/X-RAY/ULTRAVIOLET

REQUIREMENTS

- HIGH SENSITIVITY
- SPECTRAL RESOLUTION
- MINIMAL COOLING
- DETECTOR ARRAYS WHERE PRACTICAL FROM 10 TO 10^6 ELEMENTS

APPROACH

- TRANSITION CCD TECHNOLOGY TO SPACE SCIENCE APPLICATIONS
- DEVELOP MERCURY IODIDE TO MEET NEEDS WHERE SENSOR COOLING IS IMPRACTICAL



CCD IMAGE OF BETA PICTORIS

MERCURIC IODIDE CRYSTAL FOR GAMMA RAY DETECTION

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NON-COHERENT SENSORS
ACCOMPLISHMENTS

GAMMA RAY TO ULTRAVIOLET

CCD TECHNOLOGY

- TRANSFERRED TECHNOLOGY TO APPLICATIONS IN SPACE TELESCOPE, GALILEO AND AXAF PROGRAMS

MERCURY IODIDE

- DEMONSTRATED 7% SPECTRAL RESOLUTION FOR 0.661 KeV GAMMA RAYS AT ROOM TEMPERATURE

INFRARED TO MILLIMETER WAVE

- DEMONSTRATED ADVANCED DETECTOR ARRAY TECHNOLOGY BASED ON SILICON (DARK CURRENT $<10\ e^-$/sec, NOISE $<50\ e^-$)
- PIONEERING DEVELOPMENT OF GERMANIUM BIB TECHNOLOGY FOR SUBMILLIMETER
- DEMONSTRATED EXTENSION FROM 3.5 TO 5.0 μm IN COBALT SILICIDE INFRARED DETECTOR SPECTRAL RESPONSE CUTOFF

ACTIVE REMOTE SENSING

OBJECTIVES

- MAP THE DISTRIBUTION OF WIND VELOCITY, WATER VAPOR AND TRACE GASES IN THE ATMOSPHERE OF THE EARTH

TECHNOLOGY NEEDS

- SOLID STATE LASERS WITH HIGH PULSE POWER AND FREQUENCY
- CARBON DIOXIDE LASERS FOR MEASUREMENT OF DOPPLER SHIFTS OF SCATTERED RADIATION

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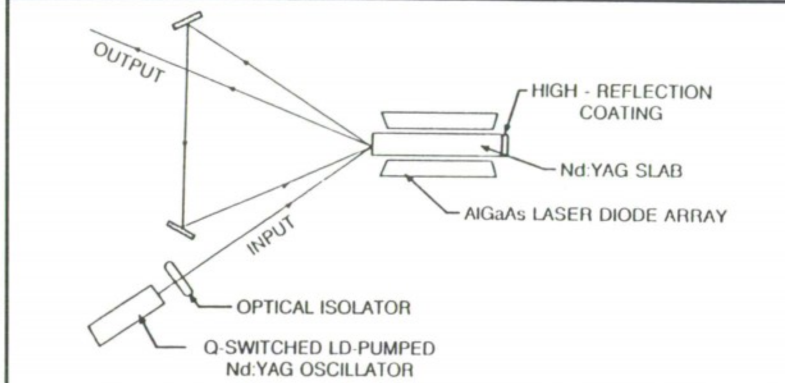
ACTIVE REMOTE SENSING
SOLID STATE LASER DEVELOPMENT

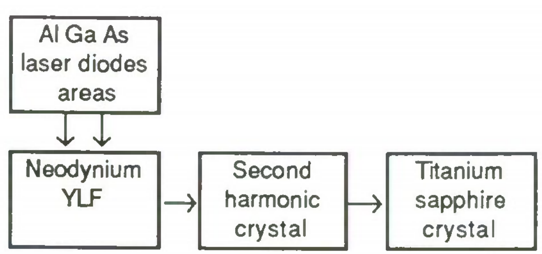
REQUIREMENTS:

- PULSE ENERGIES (~1 JOULE)
- REPETITION RATE (10 Hz)
- EFFICIENCY (>5%)
- SPECTRAL RANGE (1µm-20µm)
- SPECTRALLY TUNABLE

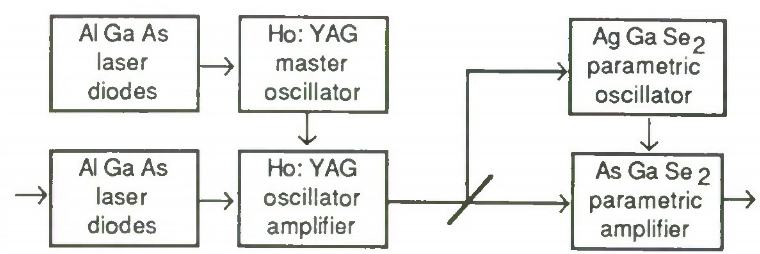
LASER DIODE-PUMPED NEODYNIUM:YAG LASER



TITANIUM: SAPPHIRE LASER



OPTICAL PARAMETRIC OSCILLATOR



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ACTIVE SENSOR RESEARCH ACCOMPLISHMENTS

CO_2 LASERS

- DEVELOPED CATALYST TECHNOLOGY FOR LONG LIFE TIME APPLICATIONS. PLANNED FOR USE IN LAWS PROGRAM

SOLID STATE LASERS

- PIONEERED DEVELOPMENT OF TITANIUM SAPPHIRE TECHNOLOGY
- CONCEIVED NEW APPROACHED FOR ACTIVE SENSING IN MID INFRA RED

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SPACE COOLER TECHNOLOGY
PROGRAM GOALS

NEEDS:

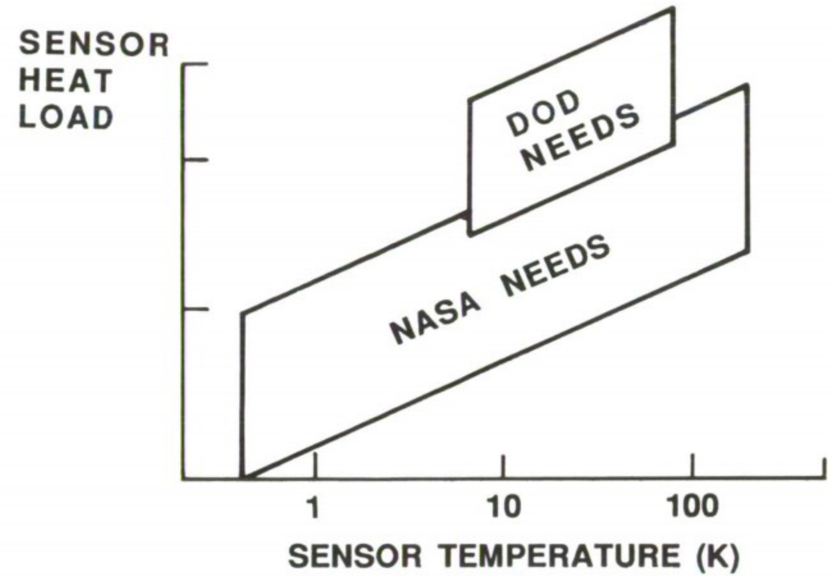
- SENSOR COOLING FROM 150K TO SUBKELVIN (<1K) TEMPERATURE

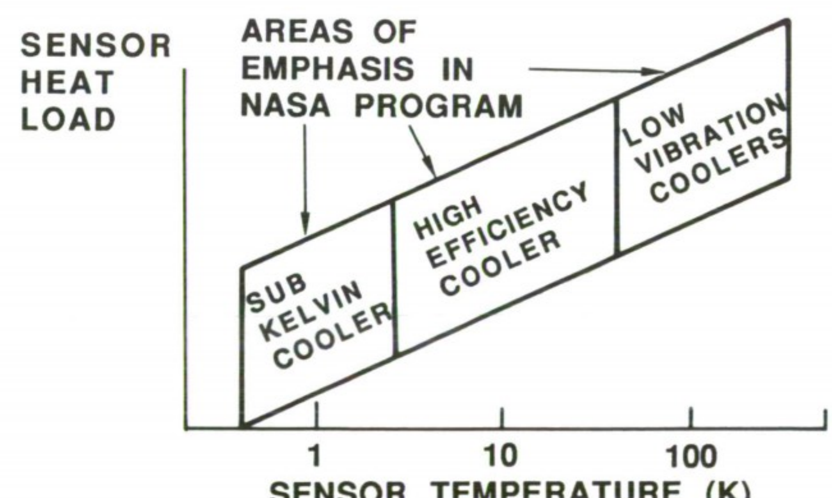
CONSTRAINTS:

- POWER AND MASS BUDGETS OF SPACECRAFT EXTREMELY TIGHT
- LONG LIFETIME AND RELIABILITY PARAMOUNT
- ULTRA LOW VIBRATION AND EMI ARE CRITICAL FOR MANY APPLICATIONS

APPROACH:

- STRESS ADVANCES IN COMPONENT TECHNOLOGY WITH ORDER-OF-MAGNITUDE PERFORMANCE IMPACT
- EXPLORE INNOVATIVE SYSTEM CONCEPTS FOR SOLVING PROBLEMS IMPOSED BY SPACE ENVIRONMENT





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SPACE COOLER TECHNOLOGY
LOW VIBRATION COOLER (65-80K)

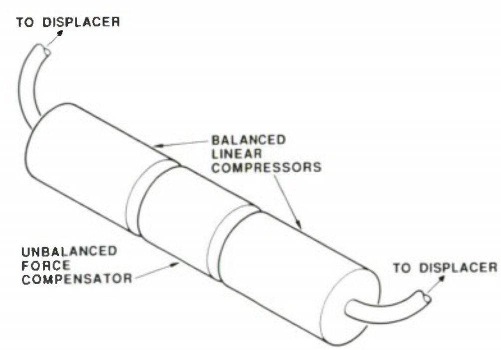
REQUIREMENTS

- COOLING TO THE RANGE FROM 10 - 150K
- LOADS UP TO 5W
- ULTRA LOW VIBRATION
- HIGH EFFICIENCY, POWER LESS THAN 200W
- LIFE TIMES > 5 YEARS

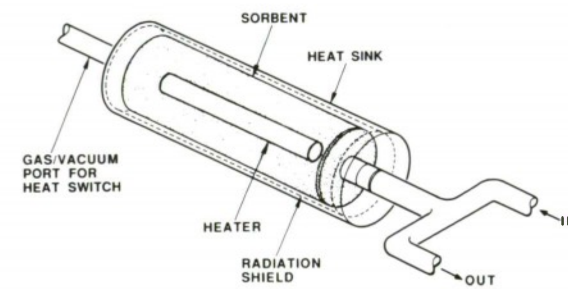
APPROACH

- DEVELOP KEY COMPONENTS OF SYSTEMS WITH POTENTIAL OF MEETING THESE REQUIREMENTS

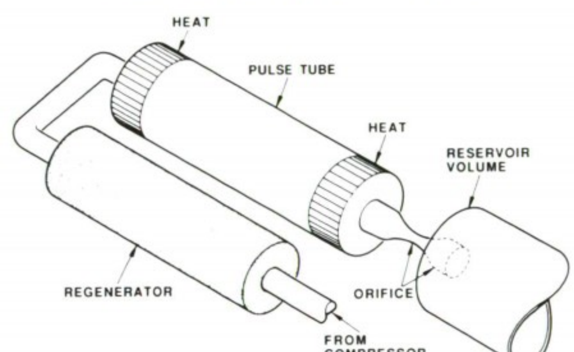
LOW VIBRATION MECHANICAL COMPRESSOR



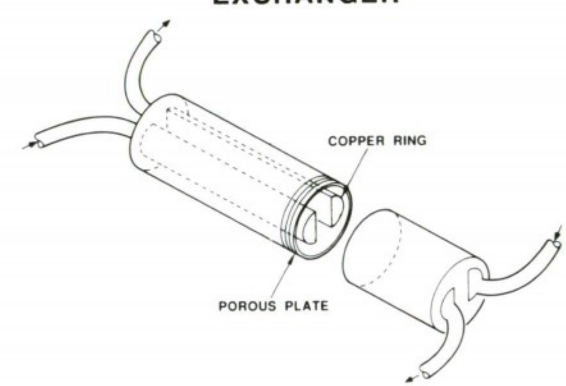
SORPTION COMPRESSOR



PULSE TUBE REFRIGERATION



RECUPERATIVE HEAT EXCHANGER



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SPACE CRYOCOOLER TECHNOLOGY

SEPARATION OF LIQUID HELIUM (^3He AND ^4He) AND VAPOR PHASE IN ZERO-G

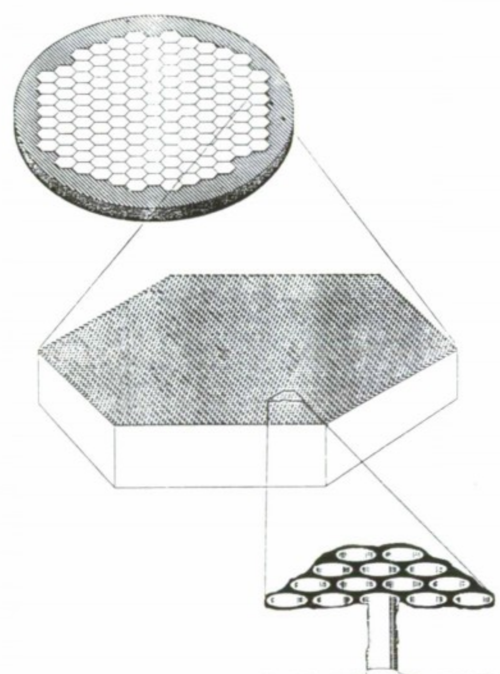
REQUIREMENTS:

- EFFICIENT SEPARATION OF LIQUID AND GAS PHASES FOR
  - → ^3He–^4He DILUTION REFRIGERATION
  - → ON ORBIT TRANSFER OF LIQUID HELIUM

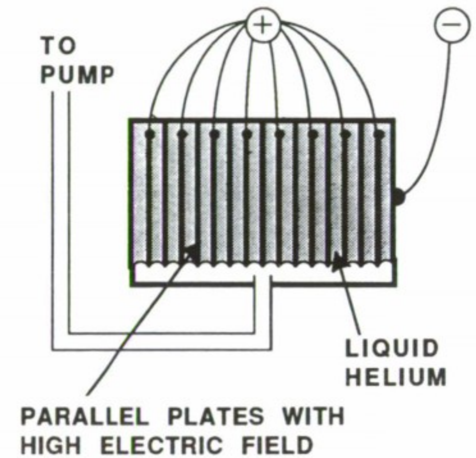
APPROACH:

- INVESTIGATE AND CHARACTERIZE NON-GRAVITATIONAL PHASE SEPARATION PHENOMENA
- FABRICATE AND DEMONSTRATE DEVICES FOR ACHIEVING PHASE SEPARATION FOR REFRIGERATOR AND CRYOGEN TRANSFER APPLICATIONS

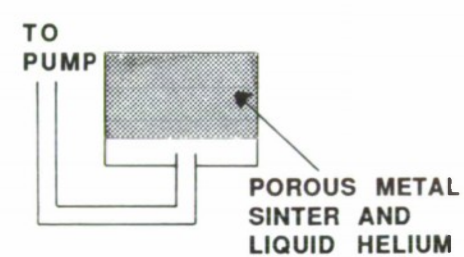
HE-II PHASE SEPARATOR



ELECTROSTATIC SEPARATION OF ^3He–^4He LIQUIDS



SURFACE TENSION SEPARATION OF ^3He–^4He LIQUIDS



NASA

SPACE COOLER RESEARCH
ACCOMPLISHMENTS

- NEW PROGRAM INITIATED IN FY 88
- FORMULATED A COHERENT MULTICENTER NASA PROGRAM TO ADDRESS SPACE SCIENCE NEEDS
- CONCEIVED SEVERAL INNOVATIVE APPROACHES FOR SUBKELVIN APPLICATIONS

NASA

SENSORS RESEARCH AND TECHNOLOGY
KEY POINTS OF CONTACT

	POINT OF CONTACT	LOCATION
PROGRAM MANAGEMENT	M.M. SOKOLOSKI	NASA/CODE RC (202) 453-2748
TECHNICAL		
CO-CHAIRMAN, SENSOR WORKING GROUP	C. McCREIGHT	AMES RESEARCH CENTER (415) 694-6549
PASSIVE COHERENT SENSING	M. FRERKING	JET PROPULSION LABORATORY (818) 354-4902
PASSIVE NON-COHERENT SENSING	C. McCREIGHT	AMES RESEARCH CENTER (415) 694-6549
ACTIVE SENSING	F. ALLARIO	LANGLEY RESEARCH CENTER (804) 865-3601
SPACE COOLER TECHNOLOGY	S. CASTLES	GODDARD SPACE FLIGHT CENTER (301) 286-8986

NASA

SENSOR RESEARCH AND TECHNOLOGY
FUTURE PLANS

- IMPLEMENTATION OF THE CSTI SCIENCE SENSOR PROGRAM

- IDENTIFY SCIENCE SENSOR NEEDS DRIVEN BY FUTURE PROGRAMS
  - ⇨ PATHFINDER - PLANETARY AND LUNAR SURFACE EXPLORATION
  - ⇨ GLOBAL CHANGE TECHNOLOGY

- IDENTIFY OPPORTUNITIES CREATED BY NEW TECHNOLOGIES
  - ⇨ OPTICS
  - ⇨ PHOTONICS
  - ⇨ HIGH T_C SUPERCONDUCTIVITY

Office of
Aeronautics and
Space
Technology

HUMANS IN SPACE

With Details on

EVA/SUIT and SPACE HUMAN FACTORS

Presentation to
" Technology for Future NASA Missions"
An AIAA/NASA OAST Conference

James P. Jenkins, Ph.D.
Program Manager for Human Factors
September 13, 1988

OBJECTIVES OF BASE RESEARCH & TECHNOLOGY

OAST

- Provide a technology for intelligent operator interfaces to meet broad NASA mission requirements

- Develop a new generation of high performance space suits, gloves, Portable Life Support Systems, and end effectors to meet requirements of advanced NASA missions

- Provide technology options and selected demonstrations to aid decision makers

EVA/SUIT PROJECT OBJECTIVES

OAST

- Determine technology requirements and capabilities for:

  ...SUIT ...PORTABLE LIFE SUPPORT SYSTEM (PLSS)

  ...GLOVES & END EFFECTORS ...MOBILITY AIDS

  ...TOOLS ...INFORMATION AND CONTROL INTERFACES

  ...LOGISTICS SUPPORT

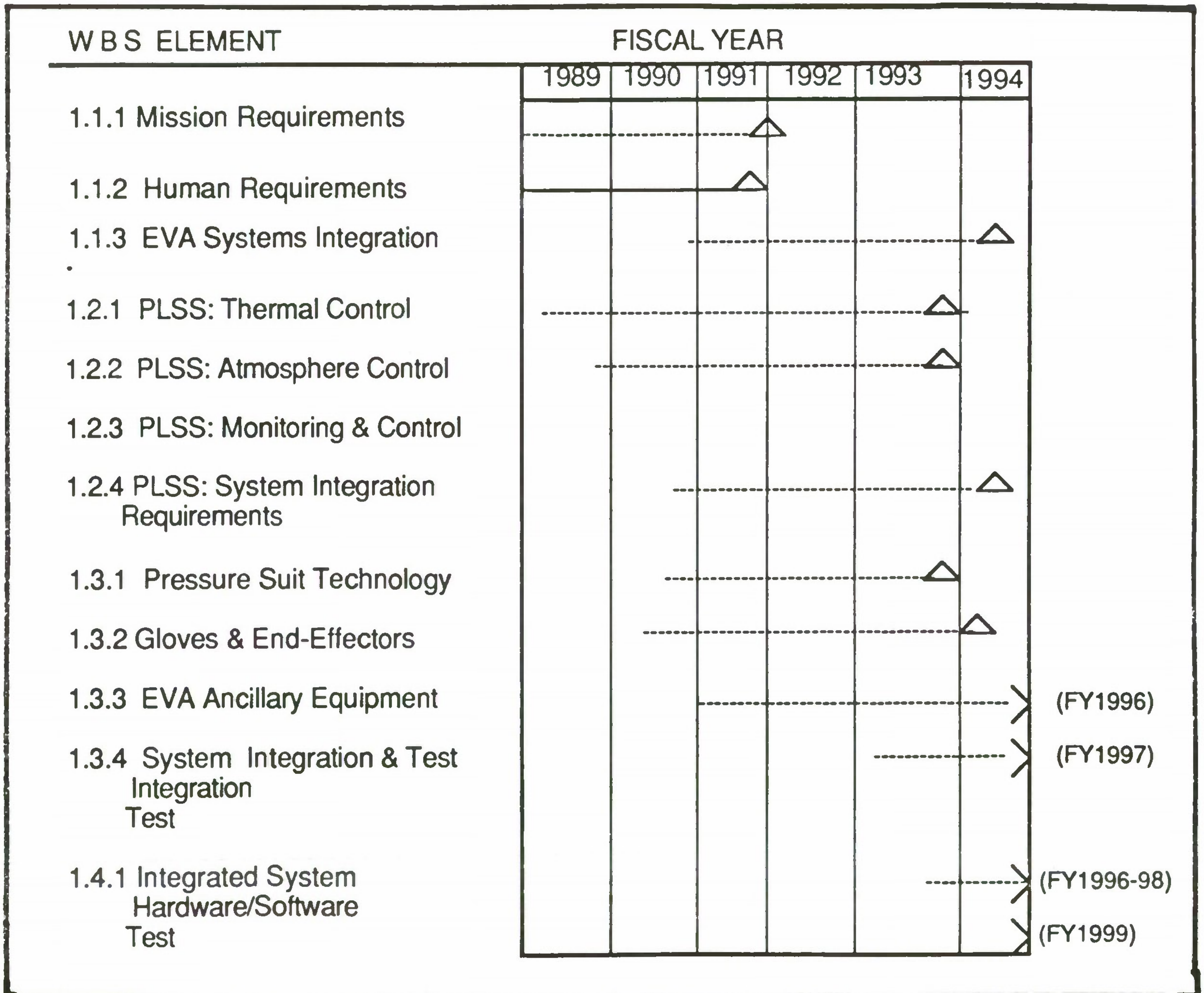
- Develop technology for above which provide levels of protection, work efficiency, reliability, maintainability, regenerability (PLSS), and mobility for PATHFINDER missions

EVA/SUIT PROJECT PRODUCTS

OAST

- Technology components, such as.....MATERIALS ...JOINT DESIGN ...COATINGS ...WEIGHT REDUCTION ...WASTE MANAGEMENT METHODS ...CONTROL SYSTEMS
- Experimental version of suit, PLSS components, gloves, and end effectors
- Functional performance requirements for suit, PLSS, gloves, end effectors, tools, mobility aids and interfaces
- Demonstrations and tests of selected technologies

SCHEDULE FOR EVA/SUIT PROGRAM



EVA/SUIT PROJECT

- NASA Centers and Points of Contact:

  Ames Research Center...Dr. Bruce Webbon, Code FL

  Langley Research Center...Mr. J. Hatfield, Code 9300

  Johnson Space Center...Mr. A. Behrends, Code EC3

- BUDGET FY 1989 - 1994.....($K)

FY1989	1990	1991	1992	1993	1994
$1,000	$2,500	$6,000	$8,000	$9,000	$10,000

XXX-000

SPACE HUMAN FACTORS OBJECTIVES

OAST

- Provide a technology base to extend or enhance human's unique capabilities to solve new problems, plan for contengencies, make sense of unfamiliar situations and process information creatively

- Meet requirements for human-machine (i.e., systems, robotics, teleoperations) compatibility

- Provide systems methods, design guidelines, tools and data bases to meet mission requirements

SPACE HUMAN FACTORS PRODUCTS

OAST

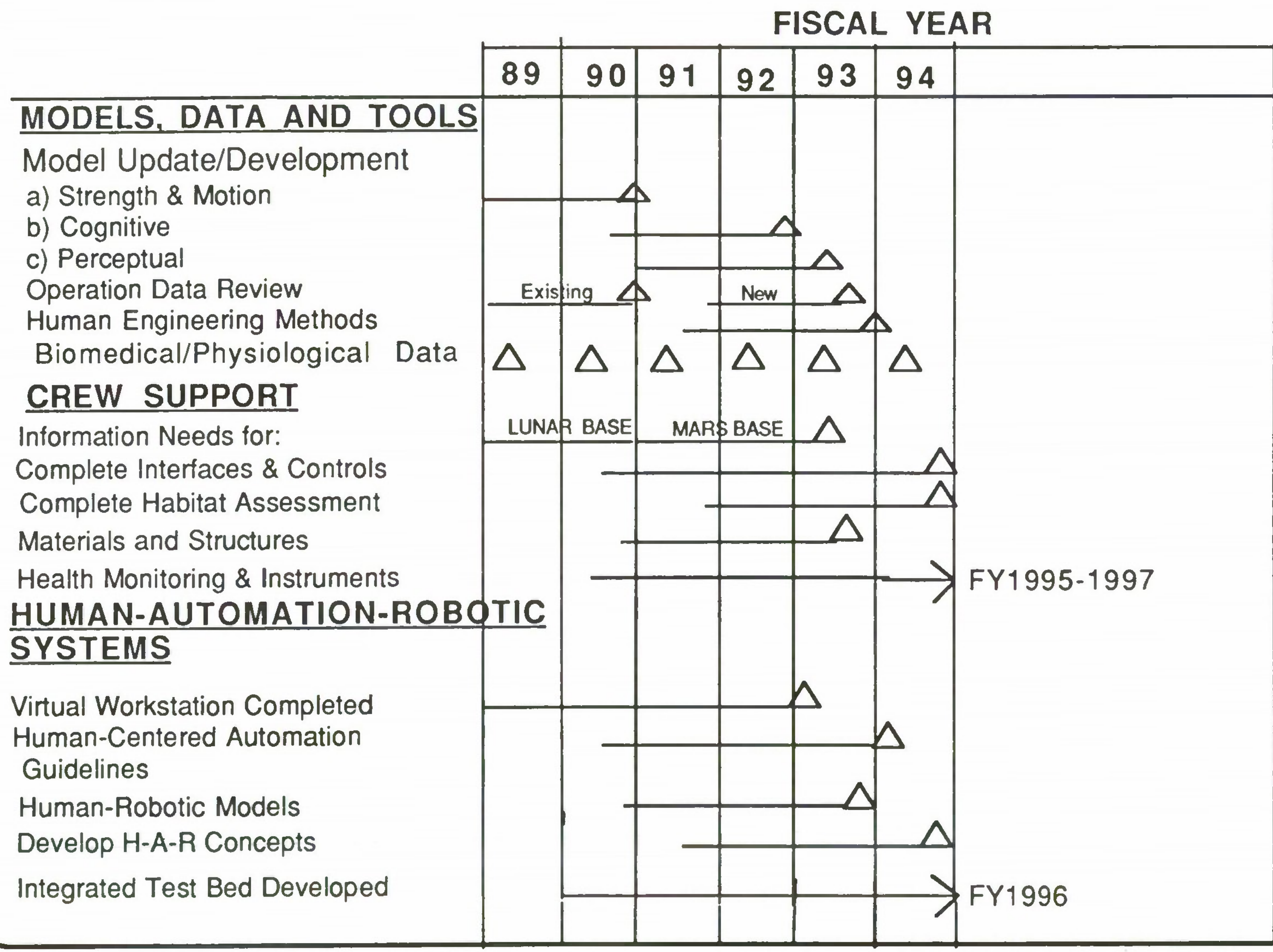
- TOOLS....such as systems design methods, design guidelines for human-machine interfaces & systems, data and data bases

- TECHNIQUES....for defining and meeting crew requirements for information display and control, living and working productively in habitats and in spacecraft, and for using all available resources

- METHODS....for enhancing human capabilities such as virtual workstations, teleoperation interfaces for human-robotic interactions, and computer-based operator aids

PATHFINDER

SPACE HUMAN FACTORS



August 1988

SPACE HUMAN FACTORS PROJECT

OAST

- NASA Centers and Points of Contact:

  Ames Research Center...Dr. M. Shafto, Code FL

  Langley Research Center...Mr. J. Hatfield, Code 9300

  Johnson Space Center...Mrs. B. Woolford, M-SD

- BUDGET FY 1989 - 1994.......($K)

FY1989	1990	1991	1992	1993	1994
$750	$1,500	$4,000	$7,000	$8,000	$10,000

NASA OFFICE OF AERONAUTICS & SPACE TECHNOLOGY

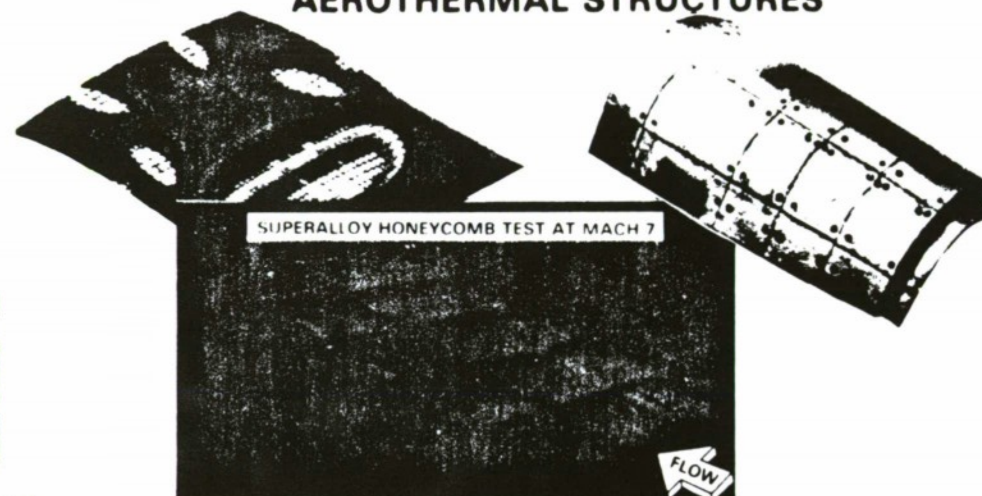
MATERIALS AND STRUCTURES DIVISION

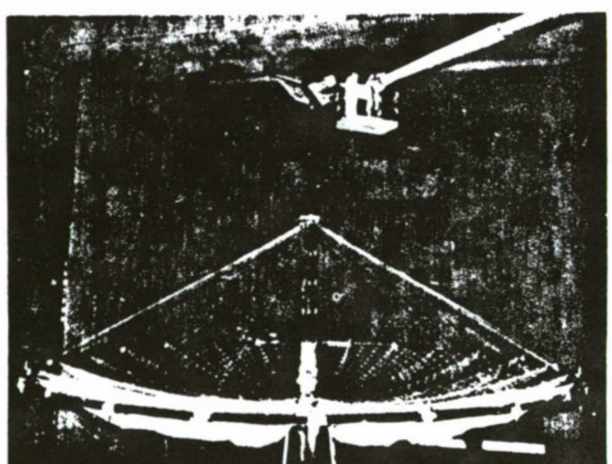
SAMUEL L. VENNERI
DIRECTOR

MATERIALS AND STRUCTURES

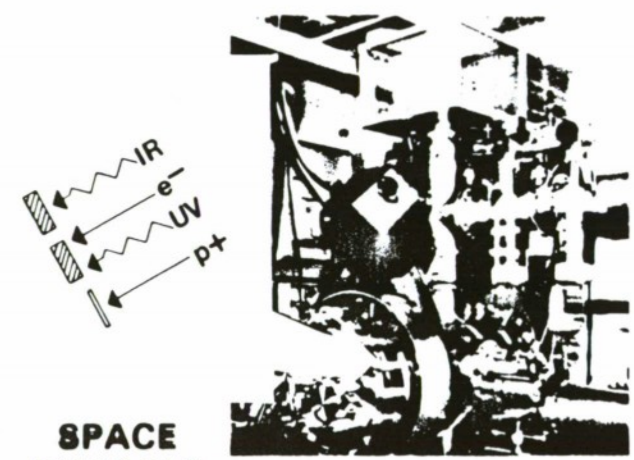
STRUCTURAL CONCEPTS

AEROTHERMAL STRUCTURES





DYNAMICS OF FLEXIBLE STRUCTURES



SPACE DURABLE MATERIALS

NASA

OAST
RM85-1288 (3)

RM 500.0

SPACE R&D BUDGET ($, M)

OAST

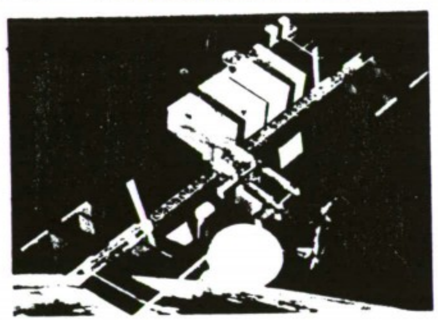
MATERIALS AND STRUCTURES DIVISION

	FY 88	FY 89	PLANNED FY 90-94
R&T BASE			
MATERIALS & STRUCTURES R&T	17.2	20.0	
CSTI			
CONTROL OF FLEXIBLE STRUCTURES	16.3	14.6	110
PRECISION SEGMENTED REFLECTORS	4.9	4.9	10
PATHFINDER			
SAMPLE ACQUISITION, ANALYSIS & PRESERVATION	-	1.0	30
IN-SPACE ASSEMBLY & CONSTRUCTION	-	1.0	35
RESOURCE PROCESSING PILOT PLANT	-	-	25

RM

SPACE MATERIALS AND STRUCTURES

SPACE STATION



SPACE TRANSPORTATION SYSTEMS

COMMUNICATION SATELLITES

CANDIDATE MATERIALS

- LIGHT ALLOYS
- METAL-MATRIX COMPOSITES
- C-C COMPOSITES
- CERAMIC-MATRIX COMP.
- COATINGS
- POLYMER FILMS
- RESIN-MATRIX COMP.

RM 500.0

SPACE ENVIRONMENTAL EFFECTS

ENVIRONMENT	ORBIT	MATERIALS & SYSTEMS AFFECTED	EXTENT
VACUUM OUTGASSING	ALL ORBITS	OPTICS, THERMAL CONTROL, ELECTRONICS	MEDIUM TERM SEVERE
ATOMIC OXYGEN & GLOW	LEO	STRUCTURAL, TRIBO, OPTIC & THERMAL CONTROL	MEDIUM, LONG TERM SEVERE CATASTROPHIC UNKNOWN
CONTAMINATION	ALL ORBITS	OPTICS, THERMAL CONTROL, ELECTRONICS	SHORT, LONG TERM SEVERE
THERMAL CYCLES	ALL ORBITS	THERMAL CONTROL, STRUCTURAL, SYSTEMS	MEDIUM TERM SEVERE CATASTROPHIC
SOLAR RADIATION	ALL ORBITS	OPTICS, THERMAL CONTROL, STRUCTURAL, ELECTRONICS	MEDIUM TERM SEVERE CATASTROPHIC
VACUUM U.V.	ALL ORBITS	OPTICS, THERMAL, STRUCTURAL, TRIBO	MEDIUM, LONG TERM SEVERE, CATASTROPHIC UNKNOWN
MICRO-METEORITES & DEBRIS	ORBIT DEPENDENT DATA LACKING	STRUCTURAL, LARGE OPTICS, PRESSURE VESSELS, SOLAR	LONG TERM SEVERE CATASTROPHIC
SPACECRAFT CHARGING	GEO, POLAR	THERMAL & OPTIC SURFACES, ELECTRONICS	SHORT, LONG TERM SEVERE, CATASTROPHIC UNKNOWN
ELECTRO-MAGNETIC INTERACTIONS AND PLASMAS	ORBIT DEPENDENT (LEO), MEO, POLAR	THERMAL & OPTIC SURFACES, ELECTRONICS, HIGH POWER	SHORT, LONG TERM SEVERE CATASTROPHIC
VAN ALLEN RADIATION	ORBIT DEPENDENT LEO, MEO, POLAR	THERMAL & OPTIC SURFACES, ELECTRONICS, STRUCTURAL	SHORT, MEDIUM, LONG TERM SEVERE

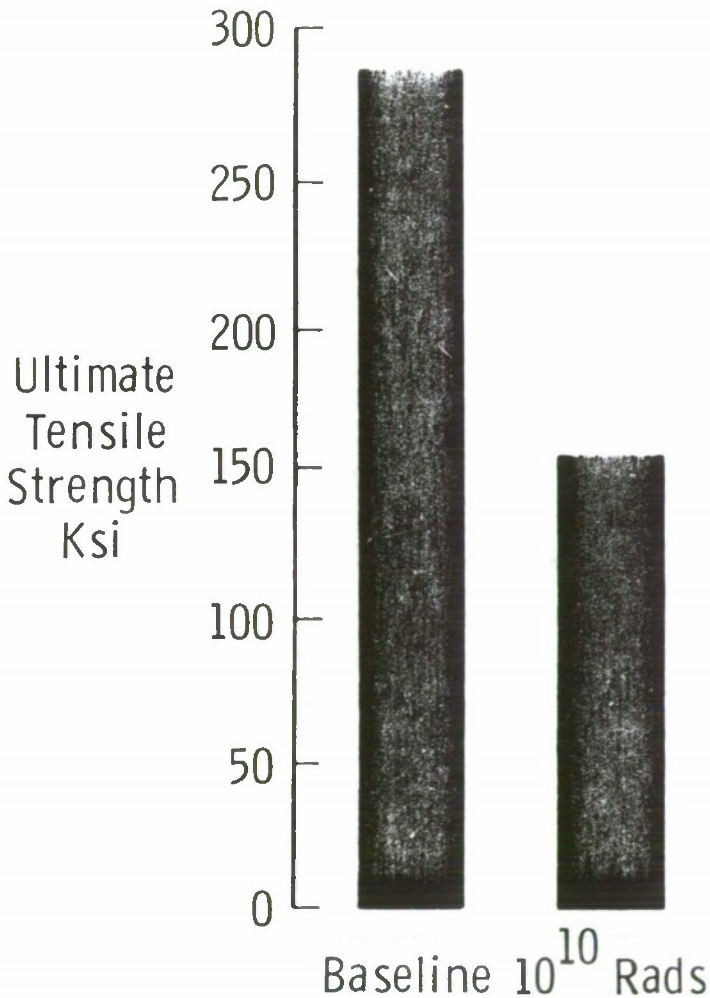
SPACE ENVIRONMENTAL EFFECTS

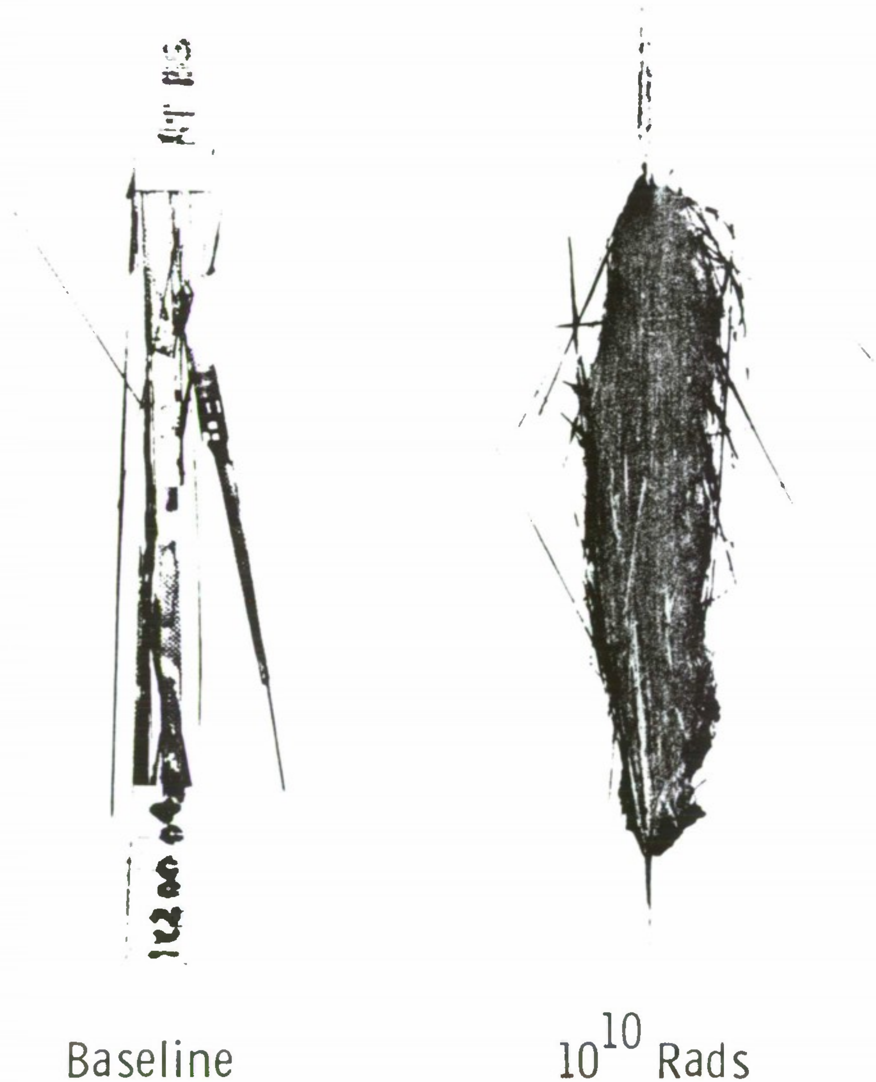
OAST

MAJOR ISSUES

- ROLE OF MATERIALS IN SYSTEMS FAILURES
- UNKNOWNS OF COMPLEX NATURAL ENVIRONMENT
- LIMITATIONS OF GROUND-BASED SIMULATION
- USE OF "OFF-THE-SHELF" MATERIALS
- ENGINEERING BASIS FOR CERTIFICATION

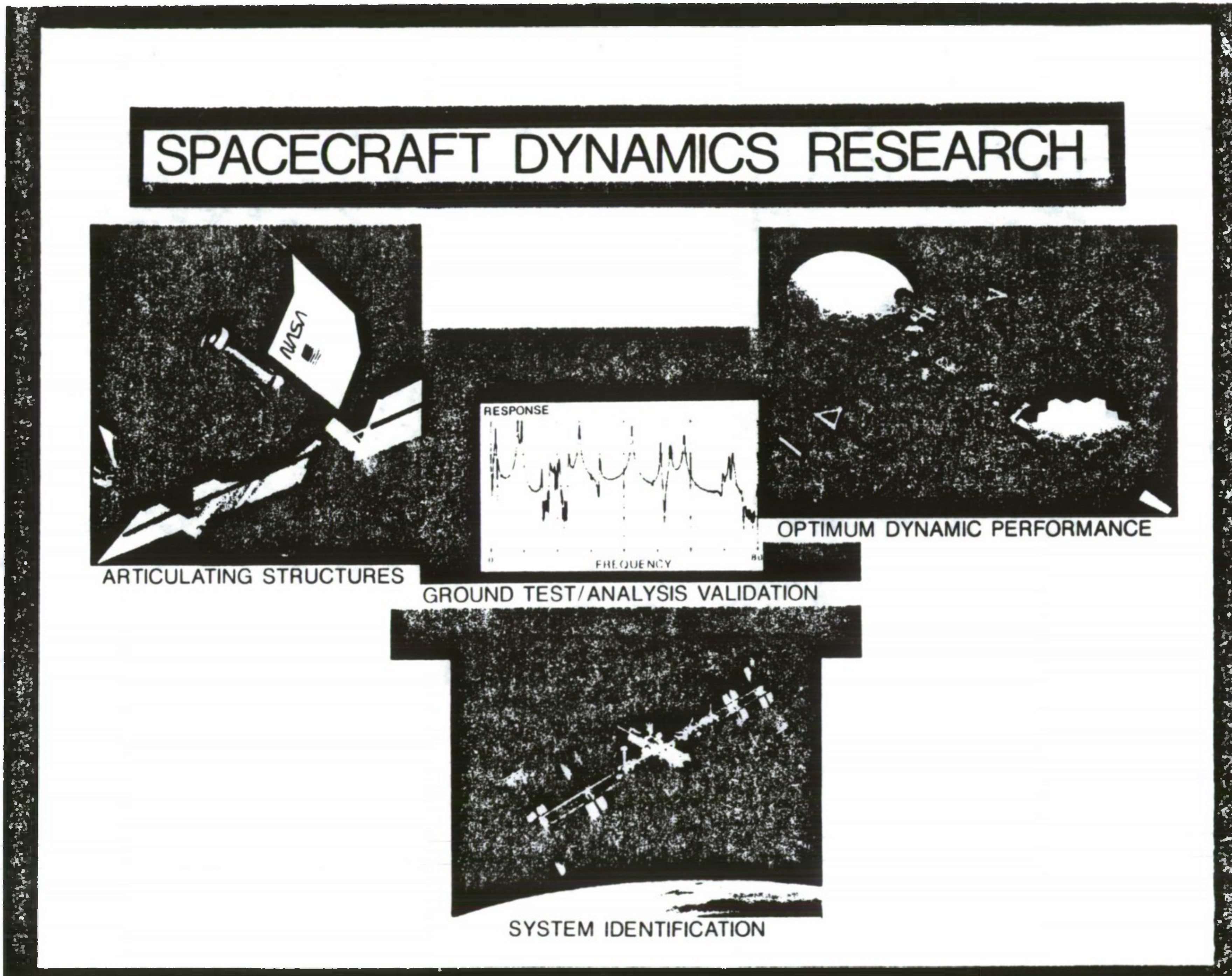
RADIATION EFFECTS ON THE TENSILE PROPERTIES OF T300/CE339 $(0)_4$ 1 MEV ELECTRONS AT 5×10^7 RADS/HR

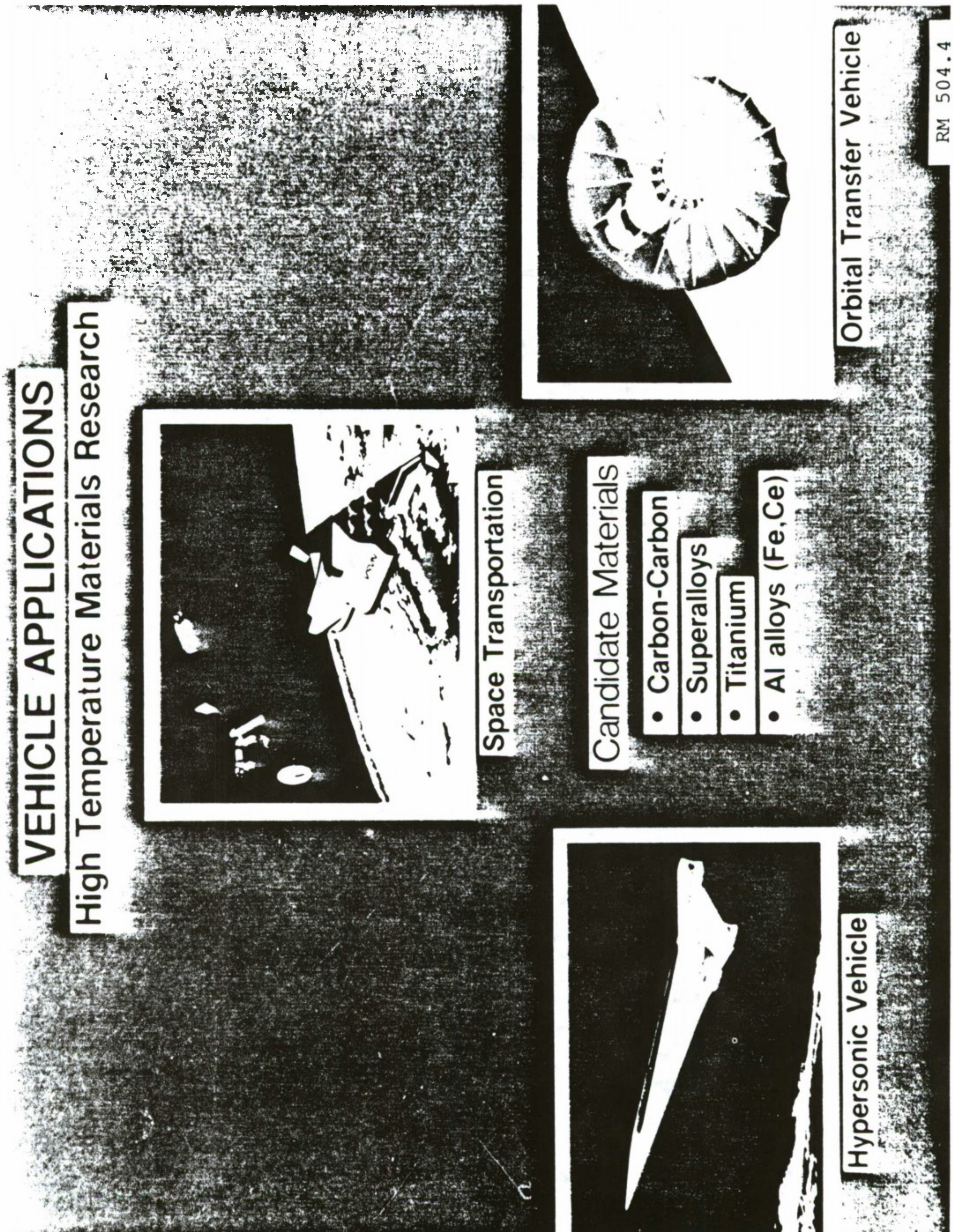




LDEF MATERIALS SPECIMENS

- Polymeric films
- Polymeric matrix composites for tensile, compression, flexure, and CTE testing
- Metal matrix composites for CTE testing
- Polished metals
- Glasses, optical filters, optical fibers
- Ceramics
- Solar cells
- Solid rocket materials


SPACECRAFT DYNAMICS RESEARCH
NASA
RESPONSE
FREQUENCY
ARTICULATING STRUCTURES
GROUND TEST/ANALYSIS VALIDATION
OPTIMUM DYNAMIC PERFORMANCE
SYSTEM IDENTIFICATION

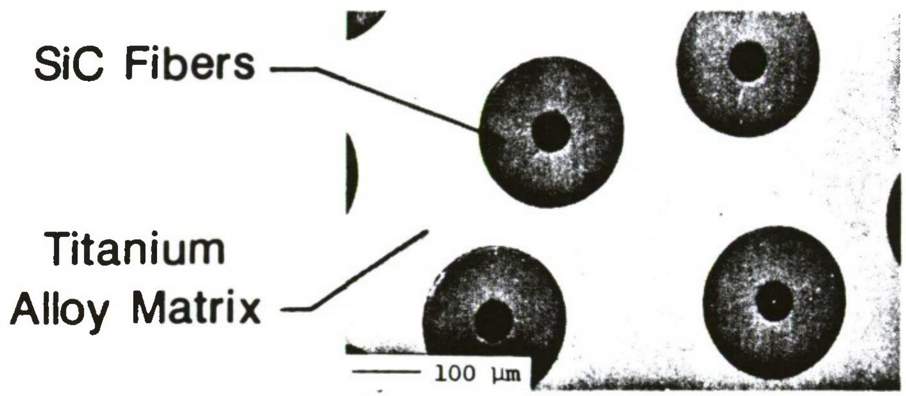

VEHICLE APPLICATIONS
High Temperature Materials Research
Space Transportation
Candidate Materials
• Carbon-Carbon
• Superalloys
• Titanium
• Al alloys (Fe,Ce)
Hypersonic Vehicle
Orbital Transfer Vehicle
RM 504.4

MATERIALS AND STRUCTURES

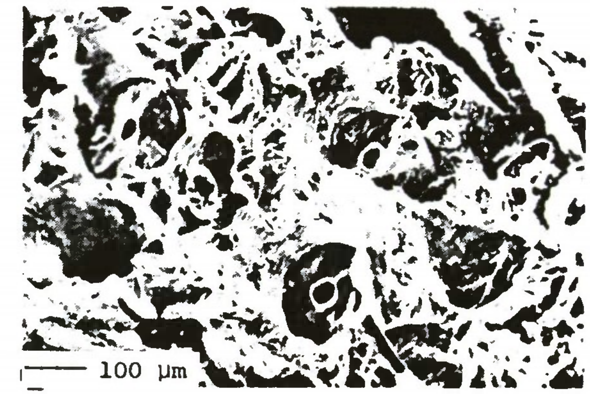
TECHNOLOGY NEEDS

- **MATERIALS**
- **STRUCTURAL CONCEPTS**
  - LEADING EDGES/NOSE CAP
  - ACTIVELY COOLED CONCEPTS
  - CONTROL CONCEPTS
  - WING
  - CRYOGENIC TANK STRUCTURE
  - SEALS
- **LOADS**
  - CONCEPTUAL WEIGHT ESTIMATION
  - AEROTHERMAL LOADS
  - AEROTHERMOELASTICITY
  - AEROACOUSTICS
  - LANDING DYNAMICS
- **TESTING**
  - COMBINED MECHANICAL, THERMAL, LH_2 LOADS
  - INSTRUMENTATION

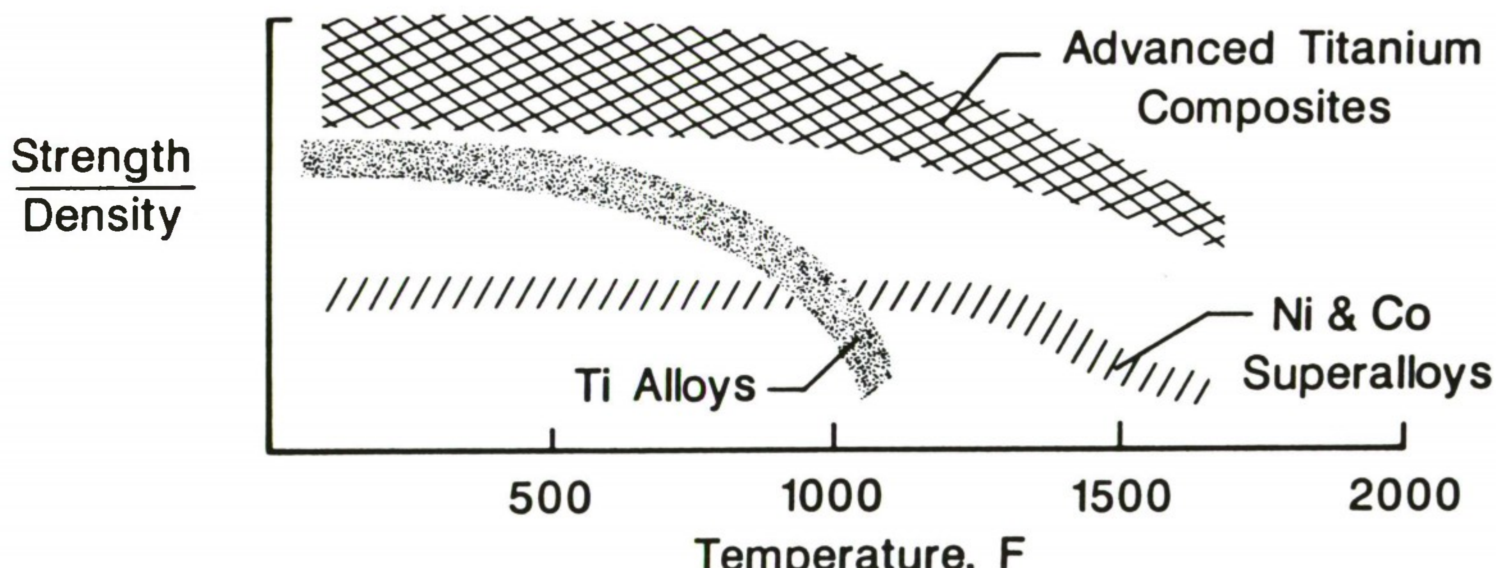
HIGH TEMPERATURE METAL MATRIX COMPOSITES
SiC FIBER REINFORCED TITANIUM ALLOYS



Polished Cross Section

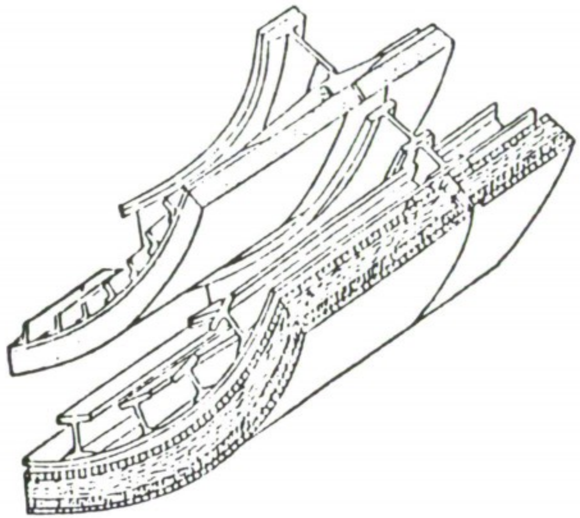


Fracture Surface

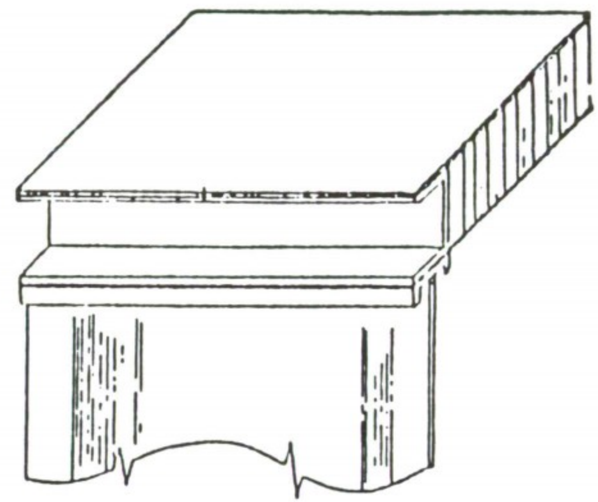


410.4

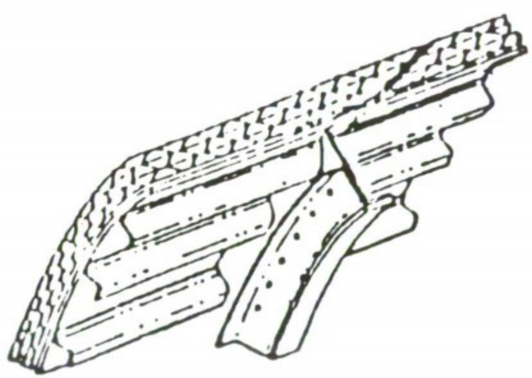
ADVANCED STRUCTURAL CONCEPTS



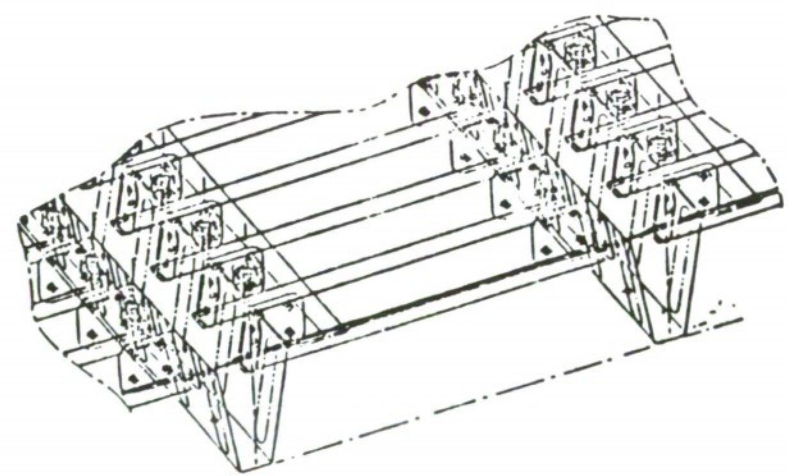
SIDEWALL CONSTRUCTION



HONEYCOMB CORE SANDWICH

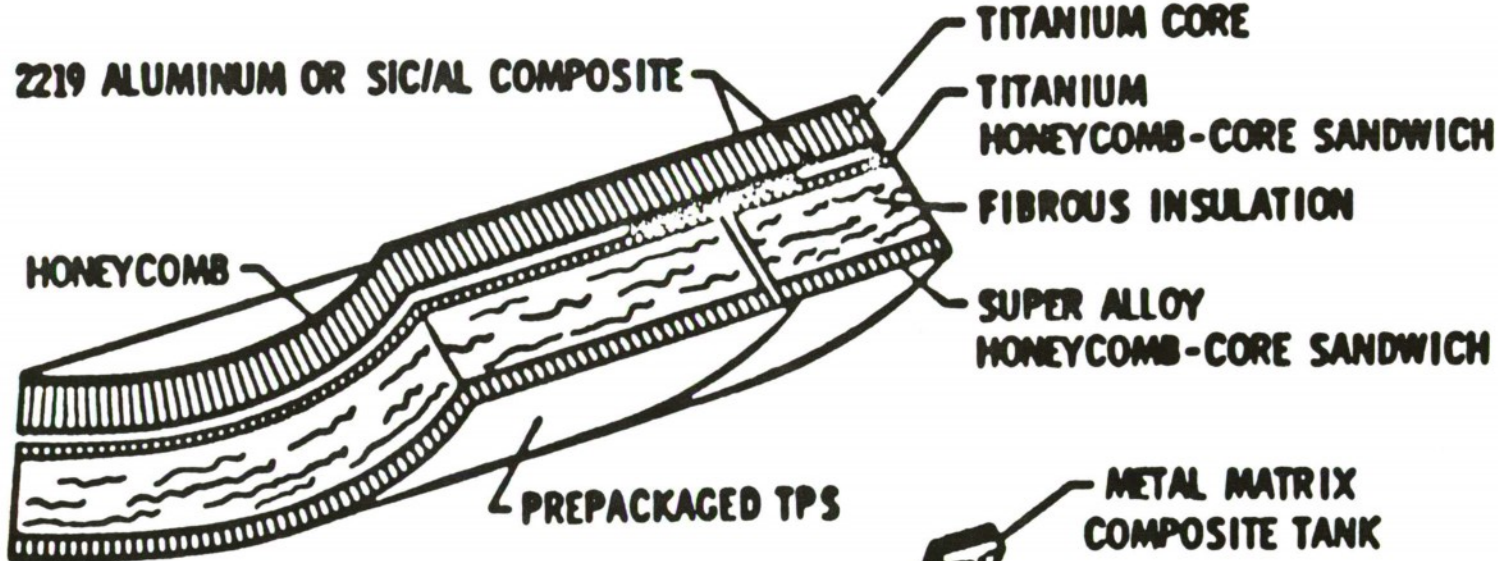


TITANIUM MULTIWALL

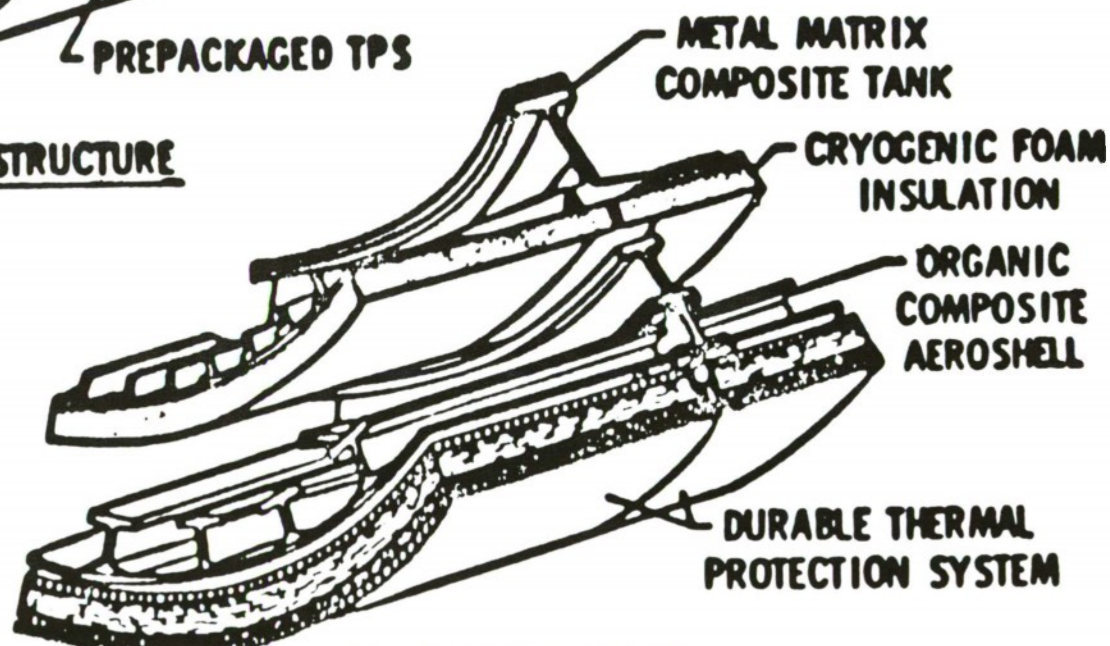


CARBON-CARBON TPS

INTEGRAL AND NON-INTEGRAL TANK STRUCTURE TPS CONCEPTS



INTEGRAL TANK STRUCTURE



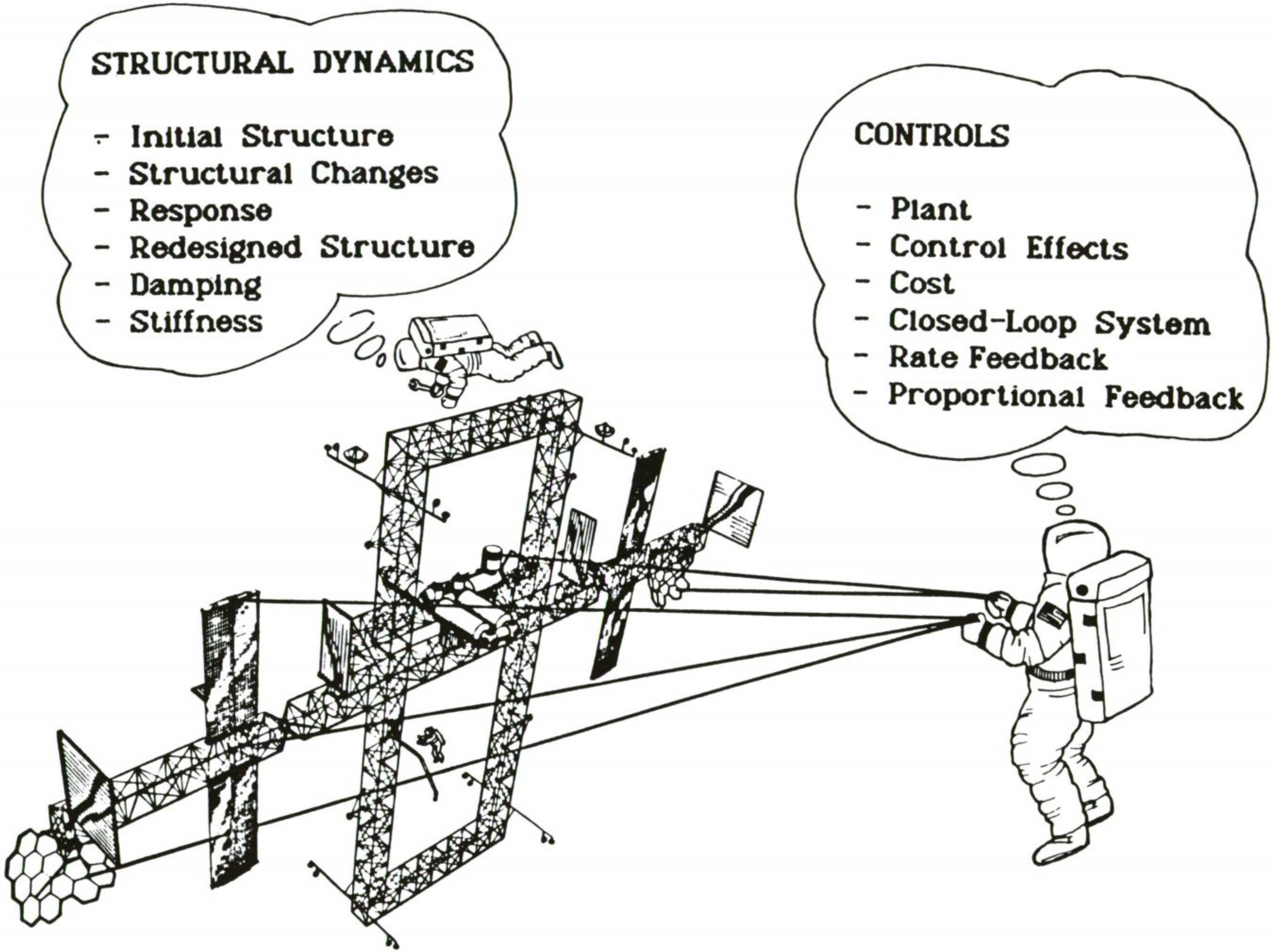
NON-INTEGRAL TANK

RM 503.0

CIVILIAN SPACE TECHNOLOGY INITIATIVE (CSTI)

LARGE SPACE STRUCTURES AND CONTROL

- CONTROL/STRUCTURE INTERACTION
- PRECISION SEGMENTED REFLECTORS


STRUCTURAL DYNAMICS
- Initial Structure
- Structural Changes
- Response
- Redesigned Structure
- Damping
- Stiffness
CONTROLS
- Plant
- Control Effects
- Cost
- Closed-Loop System
- Rate Feedback
- Proportional Feedback

RM 510.2

CONTROLS-STRUCTURES INTERACTION (CSI) TECHNOLOGY

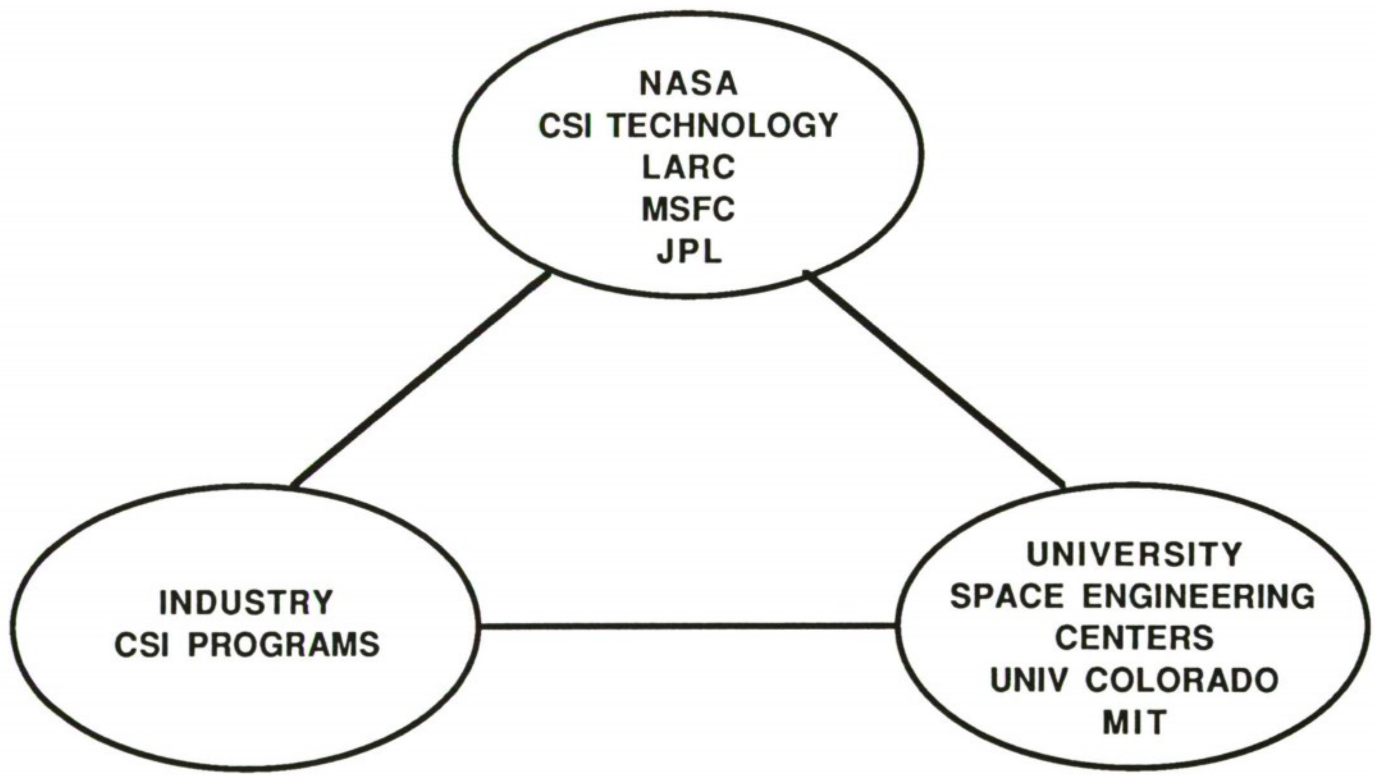
GOAL:

DEVELOP VALIDATED CSI TECHNOLOGY FOR INTEGRATED DESIGN/ANALYSIS AND QUALIFICATION OF LARGE FLEXIBLE SPACE SYSTEMS AND PRECISION SPACE STRUCTURES

OBJECTIVES:

- DEVELOP AND VALIDATE INTEGRATED DESIGN/ANALYSIS METHODS
- DEVELOP AND DEMONSTRATE GROUND TEST METHODS/TECHNIQUES TO PREDICT ON-ORBIT PERFORMANCE
- OBTAIN IN-SPACE EXPERIMENTAL DATA TO VALIDATE DESIGN/ANALYSIS AND GROUND TEST METHODS
- ESTABLISH DESIGN METHODS AND CRITERIA FOR QUALIFICATION OF SPACECRAFT FOR FUTURE SPACE MISSIONS

CONTROL-STRUCTURES INTERACTION TECHNOLOGY



CONTROL OF FLEXIBLE STRUCTURES (COFS)

MAJOR DELIVERABLES

INTEGRATED DESIGN/ANALYSIS METHODS

- INTEGRATED CONTROLS-STRUCTURES INTERACTION (CSI) DESIGN/ANALYSIS METHODOLOGY

GROUND TEST EXPERIMENTS

- CSI TESTBEDS AT LARC, JPL AND MSFC
- ACTIVE STRUCTURAL ELEMENTS WITH EMBEDDED SENSORS AND ACTUATORS

IN-SPACE FLIGHT EXPERIMENTS

- SMALL SCALE, LOW COST CSI IN-SPACE FLIGHT EXPERIMENTS
- CONTROLS AND STRUCTURES EXPERIMENT IN SPACE (CASES) SCHEDULED FOR SHUTTLE LAUNCH IN 1993

CSTI

PRECISION SEGMENTED REFLECTORS

ENABLE: LIGHTWEIGHT, THERMALLY STABLE, PRECISION SURFACES WITH ACTIVE CONTROL

GOALS:

- VALIDATED DATABASE FOR HYBRID COMPOSITE REFLECTOR MATERIALS
- LIGHTWEIGHT, LOW-COST, THERMALLY STABLE REFLECTOR PANEL WITH PRECISE SURFACE TOLERANCE
- RELIABLE SENSORS, ACTUATORS, CONTROL METHODOLOGY
- GROUND DEMONSTRATION VALIDATION OF MULTI PANEL SYSTEM

SIGNIFICANCE: TECHNOLOGY FOR CONSTRUCTION OF LARGE REFLECTORS WITH MICRON SMOOTHNESS DOES NOT EXIST. COST AND WEIGHT PENALTIES PROHIBIT USING CURRENT AND PROJECTED MATERIALS DEVELOPMENTS

OAST

JPL

PRIMARY CENTER RESPONSIBILITIES

LANGLEY RESEARCH CENTER

PRIMARY TRUSS STRUCTURE

- BASELINE PAC-TRUSS
- ERECTABLE -VS- DEPLOYABLE
- ROBOTIC COMPATIBILITY (BUT NO ACTUAL ROBOTICS)

ADVANCED PANEL MATERIALS

- ADVANCED ULTRA-LOW CTE RESINS
- GRAPHITE/GLASS COMPOSITE (ADVANCED PROCESSING)

ADVANCED MAGNETIC SUSPENSION ACTUATORS

JET PROPULSION LABORATORY

SYSTEM DEFINITION, INTEGRATION AND TEST

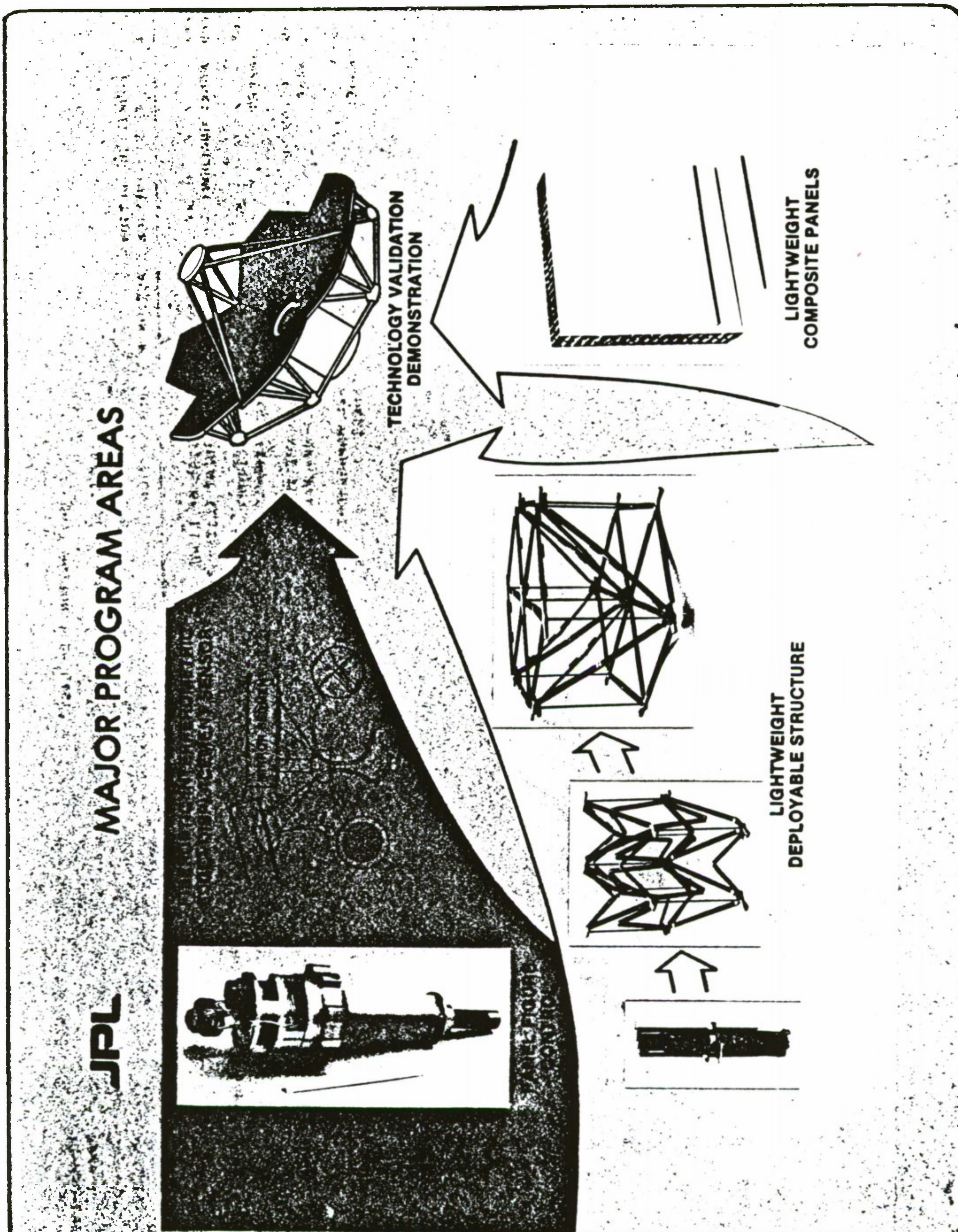
PANEL DEVELOPMENT

- CONCEPTS
  - MATERIAL SYSTEMS (BASELINE - GRAPHITE/EPOXY)
  - "DEFORMABLE" SURFACE
- SURFACE ACCURACY
- REPRODUCIBILITY (1- TO 2-METER PANELS)
- DURABILITY
- PANEL MATERIALS ADVANCED GR/EP
- COATINGS AND ADHESIVES

OVERALL CONTROL STRATEGY

- FIGURE AND VIBRATION CONTROL METHODOLOGY
- BASELINE SENSORS AND ACTUATORS

CONCEPT FOR "ACTIVE" PRIMARY STRUCTURES FOR STATIC AND DYNAMIC TUNING


JPL
MAJOR PROGRAM AREAS
TECHNOLOGY VALIDATION DEMONSTRATION
LIGHTWEIGHT COMPOSITE PANELS
LIGHTWEIGHT DEPLOYABLE STRUCTURE

PATHFINDER

- IN-SPACE ASSEMBLY AND CONSTRUCTION
- SAMPLE ACQUISITION, ANALYSIS ANDPRESERVATION
- RESOURCE PROCESSING PILOT PLANT

PATHFINDER

IN-SPACE ASSEMBLY AND CONSTRUCTION

PROGRAM OBJECTIVE:

DEVELOP TECHNOLOGY TO ENABLE THE IN-SPACE ASSEMBLY AND CONSTRUCTION FOR VARIOUS CLASSES OF SPACE STRUCTURAL CONCEPTS TO SUPPORT LONG-RANGE NASA MISSIONS

0 MARS TRANSFER VEHICLE

0 LARGE AEROBRAKES

0 DEPLOYABLE FUEL DEPOT PLATFORMS

0 PRESSURE VESSELS, HABITAT AND HANGER ENCLOSURES, FUEL TANKS

0 LUNAR CARGO VEHICLE

0 LARGE ASTRONOMICAL INSTRUMENTS

IN-SPACE ASSEMBLY AND CONSTRUCTION

MAJOR DELIVERABLES

- METHODS TELEROBOTICALLY FABRICATING PERMANENT JOINTS (E.G. WELDING)
- CONCEPT FOR HIGH-LOAD CARRYING MECHANICAL JOINTS
- "SPACE CRANE" CONCEPT FOR MANIPULATING LARGE MASSES
- ARCHITECTURE AND SPECIFICATION OF A GENERALPURPOSE, SPACE-BASED SYSTEM FOR LARGE-SCALE ASSEMBLY AND CONSTRUCTION
- VALIDATED TELEROBOTIC METHODS FOR PRECISE MANIPULATING, POSITIONING AND HOLDING OF LARGE STRUCTURAL COMPONENTS
- CONCEPT FOR LARGE-SCALE UTILITIES INSTALLATION
- VALIDATED METHODS FOR INTEGRATED TELEROBOTIC MANIPULATION, PRECISE POSITIONING AND JOINING OF LARGE, MASSIVE SPACE SYSTEMS
- SOFTWARE SYSTEM FOR IN-SPACE ASSEMBLY AND CONSTRUCTION SIMULATION, OPERATIONAL SEQUENCING AND PROCESS MONITORING

PATHFINDER

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION (SAAP)

PROGRAM OBJECTIVE:

DEVELOP THE TECHNOLOGY FOR REMOTE COLLECTION, ANALYSIS AND PRESERVATION OF EXTRA-TERRESTRIAL MATERIAL SAMPLES TO ENABLE EXPLORATION, RESOURCE IDENTIFICATION AND SITE SELECTION FOR A PILOTED MISSION (MARTIAN EMPHASIS)

- SITE AND SAMPLE SELECTION
- SAMPLE ACQUISITION
    - SURFACE SAMPLES
    - FRESH ROCK
    - SUB-SURFACE
- SAMPLE ANALYSIS
- CONTAINMENT AND PRESERVATION
- SAAP SYSTEM CONCEPTS

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

MAJOR DELIVERABLES

- MULTI-SPECTRAL REMOTE SAMPLE SENSING AND SCREENING CONCEPT
- MULTI-PURPOSE SAMPLE ACQUISITION END-EFFECTOR
- MATERIALS AND CONTAINER DESIGN FOR SAMPLE PRESERVATION
- METHODS FOR PHYSICAL/CHEMICAL ANALYSIS
- AUTOMATED ROCK CORING DRILL CONCEPT AND HARDWARE
- SAAP LABORATORY SAMPLE ACQUISITION AND PREPARATION TESTBED
- SAAP LABORATORY SAMPLE ANALYSIS TESTBED
- INTEGRATED TRANSPORTABLE SAAP "FIELD" TESTBED
- SITE SELECTION PHYSICAL/CHEMICAL DATABASE FOR A MARS MISSION
- SYSTEM CONCEPT FOR A MARS MISSION SAAP SYSTEM WITH VALIDATED TESTBED HARDWARE, AUTOMATION AND CONTROL

PATHFINDER

RESOURCE PROCESSING PILOT PLANT

PROGRAM OBJECTIVE:

DEVELOP TECHNOLOGY TO ENABLE THE EXPLOITATION OF EXTRA-TERRESTRIAL RESOURCES FOR LIFE SUPPORT, PROPULSION AND CONSTRUCTION (LUNAR EMPHASIS)

- BASIC PRODUCTION METHODS
  - OXYGEN
  - METALS
  - CONSTRUCTION MATERIALS (E.G. BRICKS, GLASS)
- PROCESS ENGINEERING
- MATERIAL PREPARATION
- PILOT PLANT DEVELOPMNENT
- MINING

MATERIALS AND STRUCTURES TECHNOLOGY

SPACE TECHNOGY NEEDS:

- SPACE DURABLE/DIMENSIONALLY STABLE MATERIALS
- ADVANCED THERMAL PROTECTION CONCEPTS
- ADVANCED SPACE STRUCTURAL CONCEPTS
  IN-SPACE CONSTRUCTION
- LARGE SPACE STRUCTURES, DYNAMICS AND CONTROL
  CONTROL-STRUCTURE INTRERACTION
- GROUND TEST/FLIGHT EXPERIMENTS METHODOLOGY

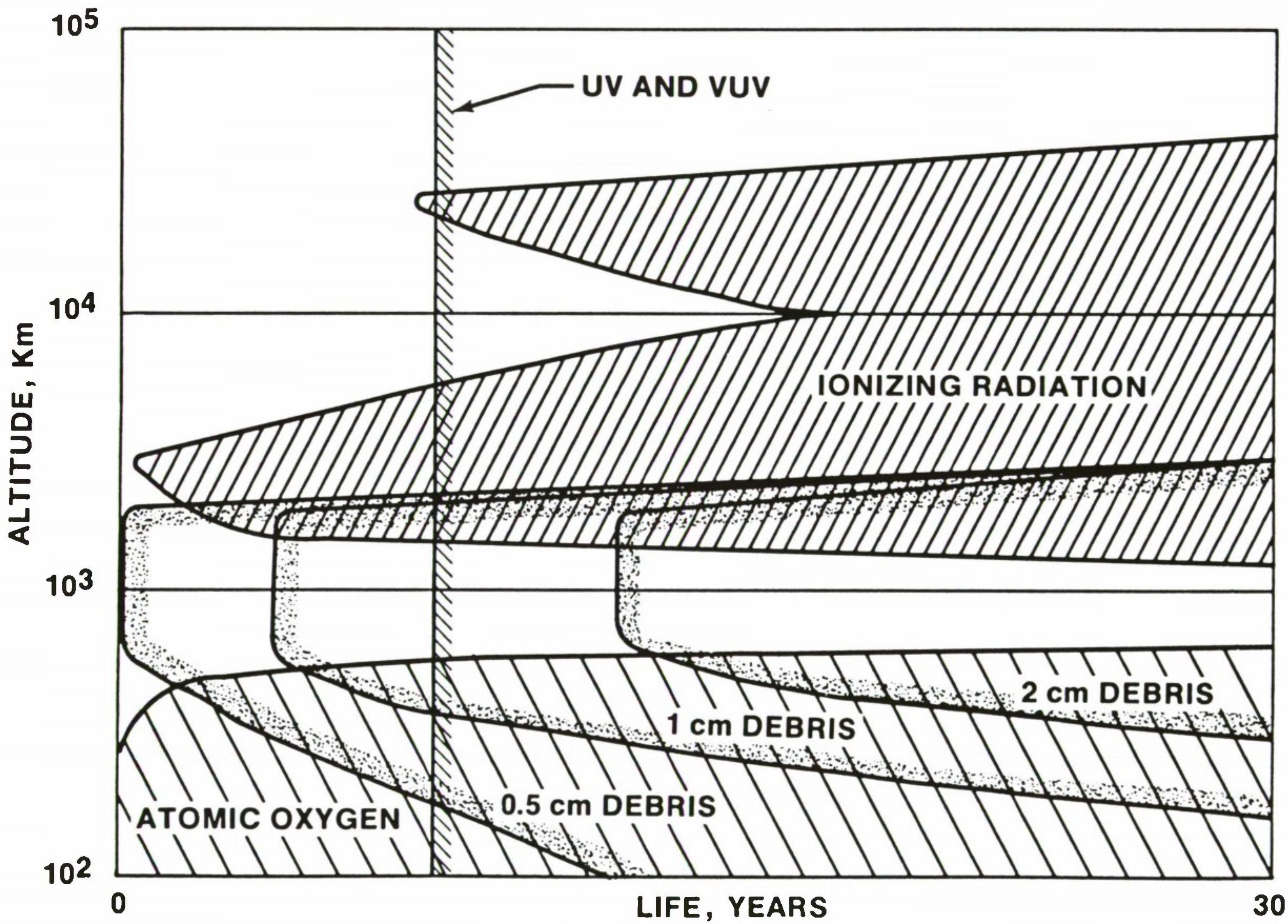
GOAL:

BROAD TECHNOLOGY BASE TO SUPPORT FUTURE NASA MISSION REQUIREMENTS

- CSTI
- PATHFINDER

IMPACT OF ENVIRONMENTAL FACTORS ON SYSTEMS

OAST



SPACE ENVIRONMENTAL EFFECTS

OAST

CONCERNS

- LARGER SPACECRAFT
- VULNERABLE LIGHTWEIGHT MATERIALS
- MINIMUM GAGE STRUCTURES
- LARGER ONBOARD POWER SOURCES
- LONGER FLIGHT DURATIONS
- HAZARDOUS ORBITS

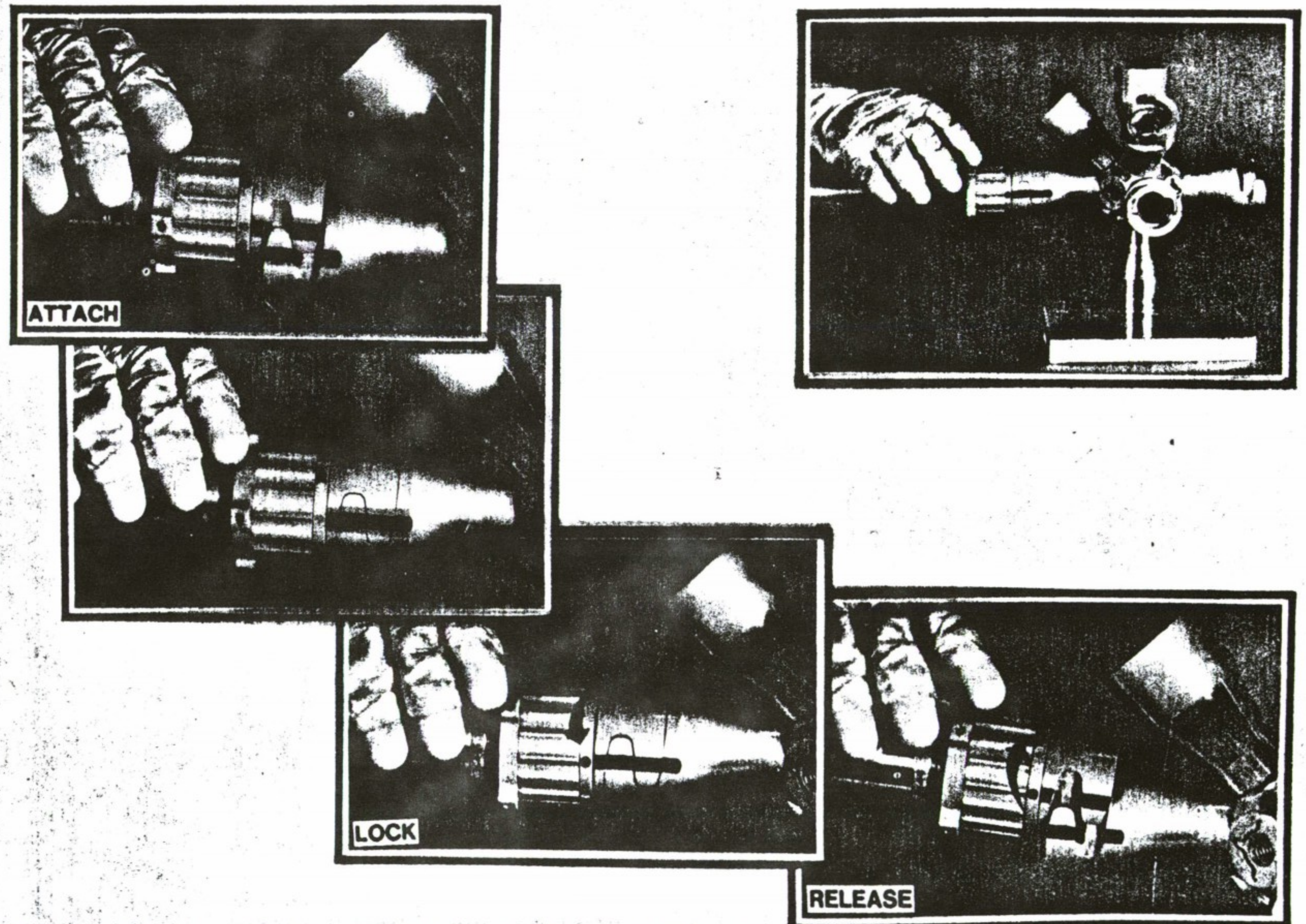
CURRENT/ADVANCED COATINGS FOR SPACECRAFT

COATING TYPE / SUBSTRATE	COATING COMPOSITION / DESIGNATION	CONCERNS
ANODIZED/ ALUMINUM ALLOYS	CHROMIC ACID ANODIZE SULFURIC ACID ANODIZE OXALIC ACID ANODIZE	THERMOMECHANICAL STABILITY
ANODIZED Al FOIL/ GRAPHITE-EPOXY COMPOSITES	CHROMIC ACID ANODIZE ON A-1100 FOIL	THERMOMECHANICAL STABILITY ADHESIVE STABILITY
WHITE PAINTS/ Al, COMPOSITES	ZINC OXIDE-SILICATE / Z-93 ZINC OXIDE-SILICONE / S13GLO ZINC ORTHOTITINATE-SILICATE / YB-71 CHEMGLAZE, A-276	THERMOMECHANICAL STABILITY ATOMIC OXYGEN
BLACK PAINTS/ Al, COMPOSITES	CHEMGLAZE, Z-306 IITRI, D=111	THERMOMECHANICAL STABILITY ATOMIC OXYGEN
THIN FILMS (<5000A)/ OPTICS, RADIATORS, SOLAR VOLTAICS	SILICON DIOXIDE ON ORGANICS ALUMINUM LEAD-TIN	ATOMIC OXYGEN DEFECT CONTENT DEBRIS IMPACT

LDEF COATINGS AND COATING SPECIMENS

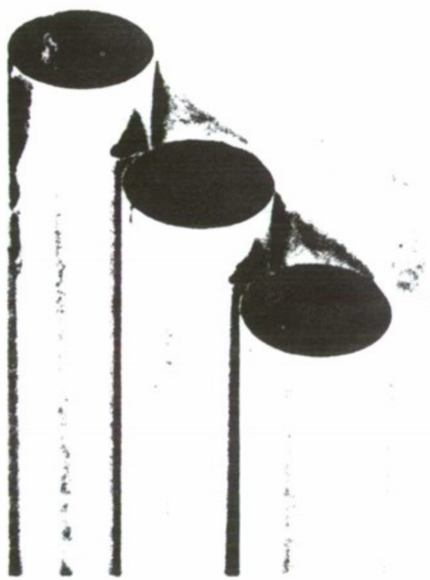
- White paints with organic and inorganic binders
- Black paints
- Anodized aluminum
- Ceramic sputter deposited coatings
- Mettallic coatings
- Second-surface mirrors
- Optical solar reflectors
- Sputter deposited coatings over graphite/epoxy

QUICK ATTACHMENT JOINT DEVELOPED FOR SPACE STATION DESIGNED FOR ASTRONAUT GLOVE HANDLING



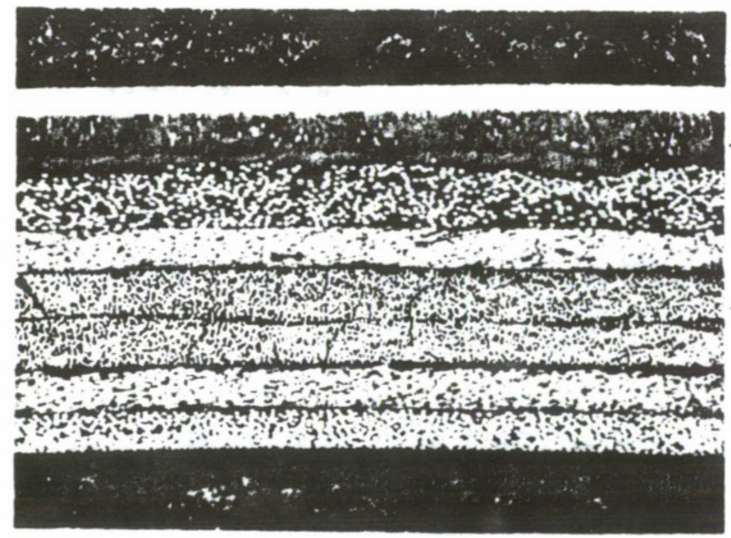
COMPOSITE TUBE WITH Al FOIL COATING

P75/934 (+60,-60,0,0,-60,+60)



COMPOSITE TUBES

2 INCH DIAMETER

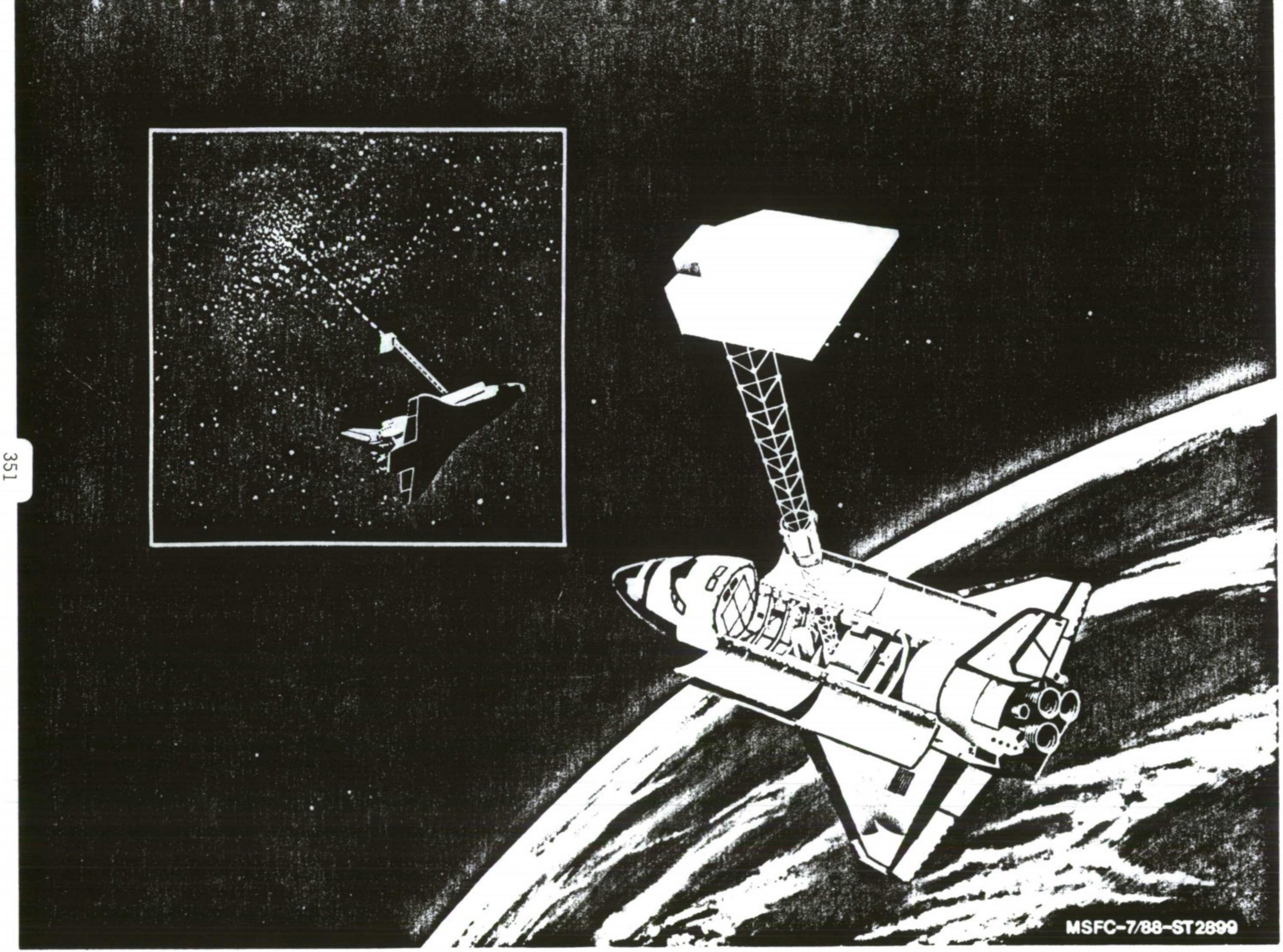


TUBE CROSS-SECTION

NASA CSI PROGRAM ELEMENTS

- CONFIGURATIONS AND CONCEPTS
- INTEGRATED ANALYSIS AND DESIGN
- GROUND TEST METHODOLOGY
- IN-SPACE FLIGHT EXPERIMENTS
- GUEST INVESTIGATOR PROGRAM

CONTROL AND STRUCTURES EXPERIMENT IN SPACE (CASES)



HYPERSONIC FLIGHT REQUIRES MATERIALS THAT ARE:

- LIGHTWEIGHT
- HIGH TEMPERATURE
- HIGH STIFFNESS AT ELEVATED TEMPERATURE
- HIGH STRENGTH AT ELEVATED TEMPERATURE
- MINIMUM GAGE
- OXIDATION RESISTANT

MATERIALS

METALLICS

- LIGHT ALLOYS AND INTERMETALLICS
- ADVANCED MMC
- PROCESSING AND JOINING

NONMETALLICS

- CARBON-CARBON
- CERAMICS
- CERAMIC MATRIX COMPOSITES

NON-STRUCTURAL MATERIALS

- SEALS AND LUBRICANTS
- COATINGS
- INSULATION

PRECISION SEGMENTED REFLECTORS
MAJOR DELIVERABLES

PANELS: 1-METER, 3-MICRON RMS PRECISION

- MATERIALS
- CONSTRUCTION
- DURABILITY

2-METER, 10-MICRON RMS, LARGE -SCALE PANEL
1-MICRON RMS, ADVANCED CONCEPT PANEL

BACK-UP TRUSS: 10-METER CONCEPT VALIDATION MODEL
4-METER TESTBED VERSION

- ERECTABLE/DEPLOYABLE
- 1-MM PRECISION
- ADVANCED HIGH-PRECISION JOINTS

CONTROLS: PANEL ALIGNMENT SYSTEM

- SUB-MICRON PRECISION
- SENSORS AND ACTUATORS
- MULTI-PANEL CONTROL ALGORITHM

"ACTIVE MEMBER" VIBRATION SUPPRESSION

MULTI-PANEL INTEGRATED TESTBED (PANELS, TRUSS, CONTROLS)

RESOURCE PROCESSING PILOT PLANT

MAJOR DELIVERABLES

- PROCESSES TO PRODUCE OXYGEN, LUNAR CONSTRUCTION MATERIALS, AND LUNAR METALS
- OXYGEN LIQUEFACTION PROCESS FOR LUNAR ENVIRONMENT
- BENEFICIATION PROCESS FOR LUNAR MATERIALS
- CONCEPTUAL DESIGN OF LUNAR PILOT PLANT
- LABORATORY PILOT PLANTS TO VALIDATE PRODUCTION OF LUNAR OXYGEN, CONSTRUCTION MATERIALS, AND METALS
- SOLIDS HANDLING AND TRANSPORT FOR LUNAR PROCESSING TESTBED, INCLUDING TELEROBOTIC CONCEPTS FOR COLLECTION, HANDLING, AND SORTING LUNAR MATERIALS
- BENCHTOP PILOT PLANTS COMPATIBLE WITH AUTONOMOUS OPERATION WHICH REQUIRE A MINIMAL DEGREE OF MONITORING AND MAINTENANCE
- LUNAR MINING CONCEPT

FLIGHT PROJECTS OVERVIEW

BY

JACK LEVINE

DIRECTOR,

OAST FLIGHT PROJECTS DIVISION

AIAA/OAST-L1 725/88

SPACE R&T STRATEGY

OAST

REVITALIZE TECHNOLOGY FOR LOW EARTH ORBIT APPLICATIONS

DEVELOP TECHNOLOGY FOR EXPLORATION OF THE SOLAR SYSTEM

MAINTAIN FUNDAMENTAL R&T BASE

BROADEN PARTICIPATION OF UNIVERSITIES

EXTEND TECHNOLOGY DEVELOPMENT TO IN-SPACE EXPERIMENTATION

FACILITATE TECHNOLOGY TRANSFER TO USERS

FLIGHT PROJECTS DIVISION

OAST — FLIGHT PROJECTS DIVISION

FUNCTIONS

- COLLABORATE WITH OAST DISCIPLINE DIVISIONS IN ANALYSES, FEASIBILITY STUDIES, EVALUATIONS, & SELECTION OF POTENTIAL FLIGHT RESEARCH & TECHNOLOGY PROJECTS
- IMPLEMENT & DIRECT CONCEPT DEFINITION STUDIES
- DIRECT APPROVED FLIGHT PROJECTS
  - EXPERIMENT DESIGN & DEVELOPMENT
  - INTEGRATION OF EXPERIMENTS WITH FLIGHT TEST VEHICLE SYSTEMS
  - FLIGHT OPERATIONS
  - DATA RETRIEVAL, ANALYSIS, DISSEMINATION

AIAA/OAST-L3c 8/24/88

CURRENT SPACE FLIGHT EXPERIMENTS

OAST — FLIGHT PROJECTS DIVISION

FLIGHT EXPERIMENTS	HQ		LEAD CENTER
LONG DURATION EXPOSURE FACILITY	JOHN LORIA	—	LANGLEY
ORBITER EXPERIMENTS	RICHARD GUALDONI	—	JOHNSON
LIDAR IN-SPACE TECHNOLOGY EXPERIMENT	RICHARD GUALDONI	—	LANGLEY
ION AUXILIARY PROPULSION SYSTEM	JOHN LORIA	—	LEWIS
ARCJET FLIGHT EXPERIMENT	JOHN LORIA	—	LEWIS
TELEROBOT INTELLIGENT INTERFACE FLIGHT EXPERIMENT	CLOTAIRE WOOD	—	JPL
CRYOGENIC FLUID MANAGEMENT FLIGHT EXPERIMENT	JOHN LORIA	—	LEWIS
OUT-REACH (INDUSTRY/UNIVERSITY TECHNOLOGY EXPERIMENTS)	JON PYLE		
IN-REACH (NASA TECHNOLOGY EXPERIMENTS)	JON PYLE		
AEROASSIST FLIGHT EXPERIMENT	JOHN SMITH	—	MARSHALL

AIAA/OAST-L4a 9/2/88

LDEF

LONG DURATION EXPOSURE FACILITY

OAST FLIGHT PROJECTS DIVISION

OBJECTIVES:

- DETERMINE LONG-TERM SPACE EXPOSURE EFFECTS ON MATERIALS, COATINGS, & OPTICS
- MEASURE SPACE ENVIRONMENTAL PHENOMENA OVER EXTENDED TIME

STATUS:

- 34 EXPERIMENTS ADVERSELY AFFECTED BY LDEF RECOVERY DELAY
- 23 EXPERIMENTS EITHER IMPROVED OR NOT AFFECTED
  - COMPOSITE MATERIALS
  - PHASED ARRAY ANTENNA MATERIALS
  - HOLOGRAPHIC DATA STORAGE CRYSTALS
  - SOLAR ARRAY MATERIALS
  - GLASS MATERIALS
- LDEF STRUCTURE AVAILABLE FOR STUDY OF ENVIRONMENTAL EROSION & DEBRIS IMPACT
- SCHEDULED FOR RETRIEVAL - NOVEMBER 1989

LEAD CENTER CONTACT:

- ROBERT L. JAMES, JR.
  LANGLEY RESEARCH CENTER
  PHONE NO. (804) 865-4987

AIAA/OAST-L10a 8/22/88

OEX

OBITER EXPERIMENT PROGRAM

OAST — FLIGHT PROJECTS DIVISION

OBJECTIVES:

- OBTAIN BASIC AEROTHERMODYNAMIC & ENTRY ENVIRONMENT DATA FROM R&D INSTRUMENTATION INSTALLED IN SPACE SHUTTLE ORBITER
- FLIGHT-VALIDATE GROUND TEST RESULTS TO IMPROVE BASIS FOR DESIGN OF ADVANCED SPACECRAFT

STATUS:

- DATA COLLECTION ON-GOING SINCE 1985 - WILL CONTINUE INTO 1990'S
- SOME EXPERIMENTS STILL TO BE DESIGNED & DEVELOPED

LEAD CENTER CONTACT:

- ROBERT SPANN
  JOHNSON SPACE CENTER
  PHONE # (713) 483-3022

AIAA/OAST-LM21a 8/18/88

OEX

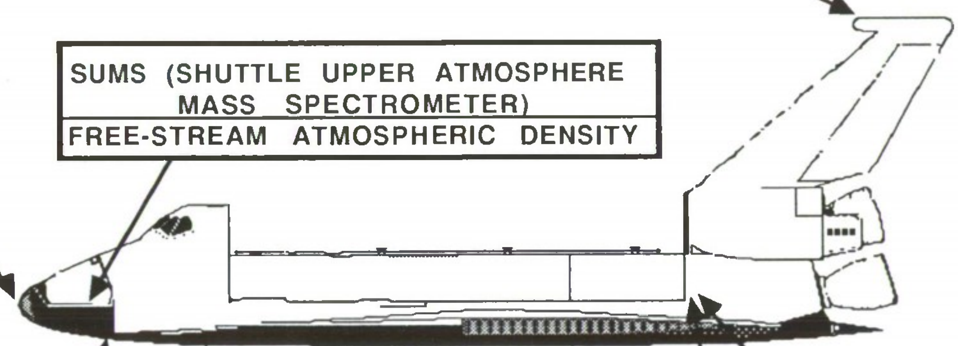
OBITER EXPERIMENT PROGRAM

OAST — FLIGHT PROJECTS DIVISION

SEADS (SHUTTLE ENTRY AIR DATA SYSTEM)
PRECISE MEASUREMENT OF VEHICLE ATTITUDE, STATE

SUMS (SHUTTLE UPPER ATMOSPHERE MASS SPECTROMETER)
FREE-STREAM ATMOSPHERIC DENSITY

SILTS (SHUTTLE INFRARED LEESIDE TEMP. SENSING)
UPPER SURFACE AERO HEATING



ACTPS (ADVANCED CERAMIC THERMAL PROTECTION SYSTEM)
EVALUATE ADV. THERMAL PROTECTION MATERIALS

TGHE (TILE GAP HEATING EFFECTS)
DATA FOR TILE GAP OPTIMIZATION

CSE (CATALYTIC SURFACE EFFECTS)
VERIFY THERMAL PROTECTION SYSTEM DESIGN

AIP (AEROTHERMAL INSTRUMENTATION PKG.)
ENTRY TEMPERATURE, PRESSURES

OARE (ORBITAL ACCELERATION RESEARCH EXPERIMENT)
ORBITAL DECELERATION FOR AERODYNAMICS IN FREE-MOLECULE FLOW

ACIP (AERODYNAMIC COEFFICIENT IDENTIFICATION PKG)
HIRAP (HIGH RESOLUTION ACCELEROMETER PKG)
AERODYNAMIC DATA

AIAA/OAST-L21c 8/22/88

LITE

LIDAR IN-SPACE TECHNOLOGY EXP.

OAST — FLIGHT PROJECTS DIVISION

OBJECTIVE:

- EVALUATE CRITICAL ATMOSPHERIC PARAMETERS & VALIDATE OPERATION OF A SOLID-STATE LIDAR SYSTEM FROM A SPACEBORNE PLATFORM, MEASURING:
  - CLOUD DECK ALTITUDES
  - PLANETARY BOUNDARY-LAYER HEIGHTS
  - STRATOSPHERIC & TROPOSPHERIC AEROSOLS
  - ATMOSPHERIC TEMPERATURE & DENSITY (10KM TO 40KM)

STATUS:

- LASER TRANSMITTER MODULE, CASSEGRAIN TELESCOPE, & ENVIRONMENTAL MONITORING SYSTEM IN DEVELOPMENT
- FLIGHT MANIFESTED FOR 1993

LEAD CENTER CONTACT:

- RICHARD R. NELMS
  LANGLEY RESEARCH CENTER
  PHONE NO. (804) 865-4947

AIAA/OAST-L23 8/22/88

IAPS

ION AUXILIARY PROPULSION SYSTEM

OBJECTIVES:

- EVALUATE & VALIDATE ION AUXILIARY PROPULSION SYSTEM ON A FUNCTIONAL SPACECRAFT
  - MERCURY PROPELLANT
  - 0.2 KW, 1mLB THRUST, Isp 2700
- DEMONSTRATE LONG-LIFE CONTROL OF A SPACECRAFT

STATUS:

- ON MANIFEST FOR STS FLIGHT #37 (1990) ON TEAL RUBY SPACECRAFT
- SPACECRAFT INTEGRATION & TESTING COMPLETED

LEAD CENTER CONTACT:

- LOU IGNACZAK
  LEWIS RESEARCH CENTER
  PHONE NO. (216) 433-2848

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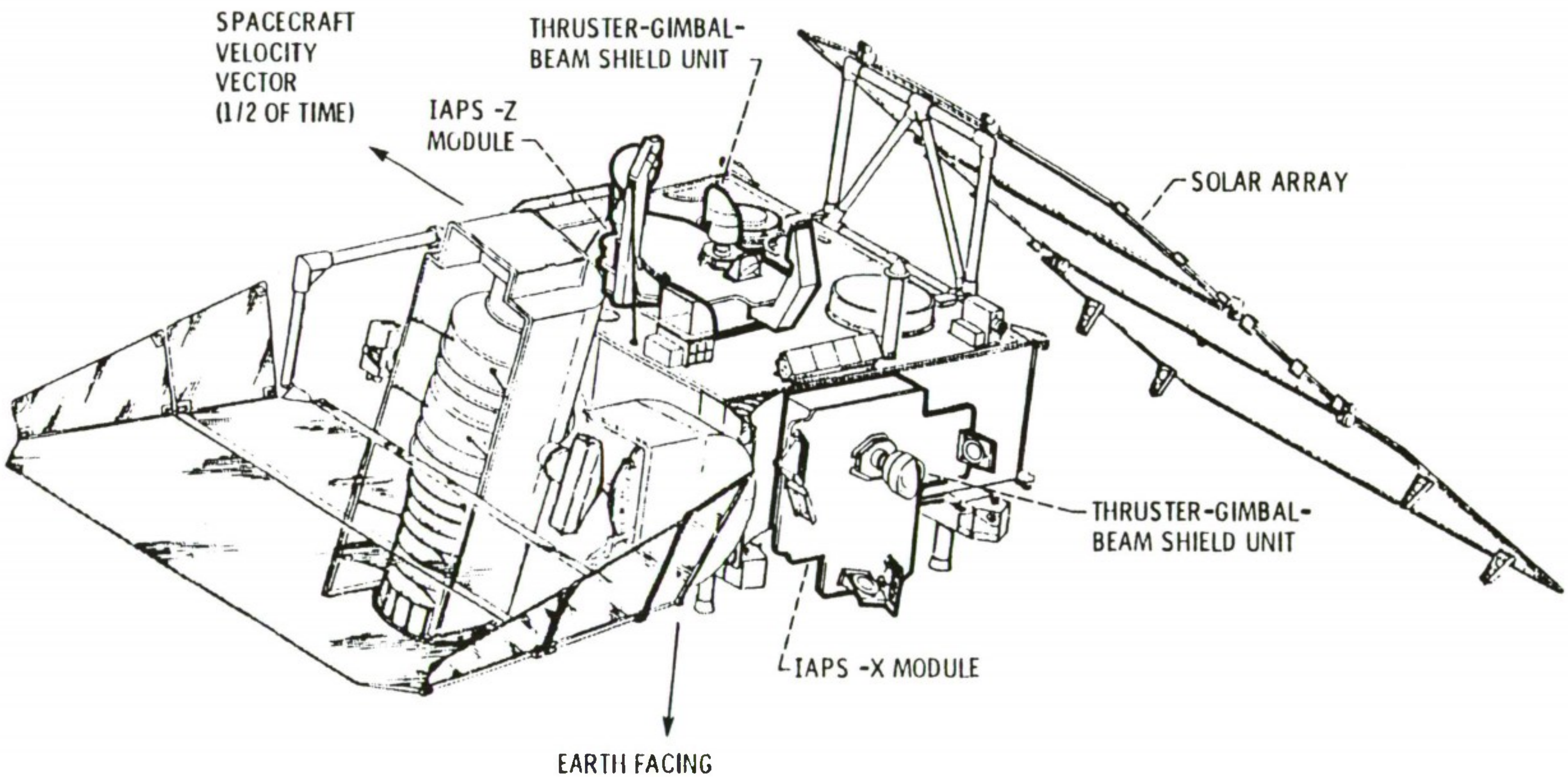
IAPS

ION AUXILIARY PROPULSION SYSTEM



IAPS ON TEAL RUBY SATELLITE

ARCJET FLIGHT EXPERIMENT

OAST — FLIGHT PROJECTS DIVISION

OBJECTIVES:

- ASSESS ARCJET AUXILIARY PROPULSION SYSTEM OPERATION IN SPACE ENVIRONMENT
  - HY DRAZINE PROPELLANT
  - 1.4 KW, 50 mLB THRUST, Isp 450
- EVALUATE PLUME EFFECTS & THRUSTER/THERMAL INTERACTIONS ON A COMMERICAL COMMUNICATIONS SATELLITE

STATUS:

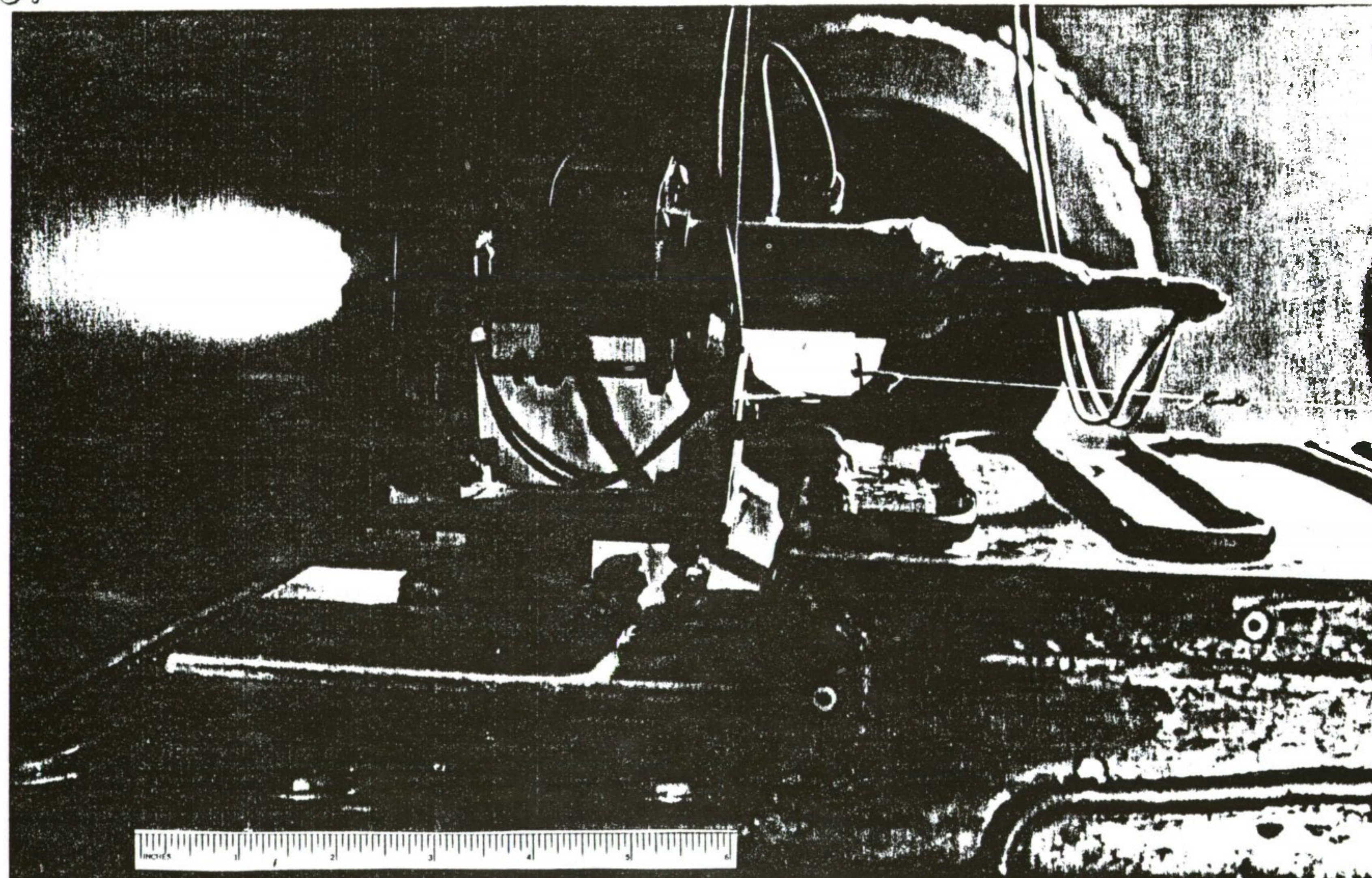
- PRELIMINARY DESIGN & ARCJET COMPONENT DEVELOPMENT COMPLETED
- FLIGHT HARDWARE DESIGN, DEVELOPMENT & TESTING SCHEDULED TO START IN 1989
- FLIGHT TEST TENTATIVELY PLANNED FOR 1991

LEAD CENTER CONTACT:

- JERRI S. LING
  LEWIS RESEARCH CENTER
  PHONE NO. (216) 433-2841

AIAA/OAST-L19b8/29/88

ARCJET FLIGHT EXPERIMENT



TRIIFEX

TELEROBOTIC INTELLIGENT INTERFACE FLIGHT EXPERIMENT

OBJECTIVES:

- EVALUATE & VALIDATE TELEOPERATION OF A ROBOTIC MANIPULATOR UNDER CONDITIONS OF MICRO-G & COMMUNICATION TIME DELAYS
- VALIDATE ADVANCED SPACE TELEROBOT CONTROLS INCLUDING HIGH-FIDELITY HYBRID POSITION & FORCE CONTROL TECHNIQUES

STATUS:

- CONCEPTUAL DESIGN IN PROGRESS AT JPL
- DEVELOPMENT & INTEGRATION SCHEDULED TO START IN LATE 1988
- FLIGHT TEST PLANNED IN COMBINATION WITH GERMAN ROTEX EXPERIMENT ON SPACELAB D-2 MISSION (1991)

LEAD CENTER CONTACT:

- DANIEL KERRISK
  JET PROPULSION LABORATORY
  PHONE NO. (818) 354-2566

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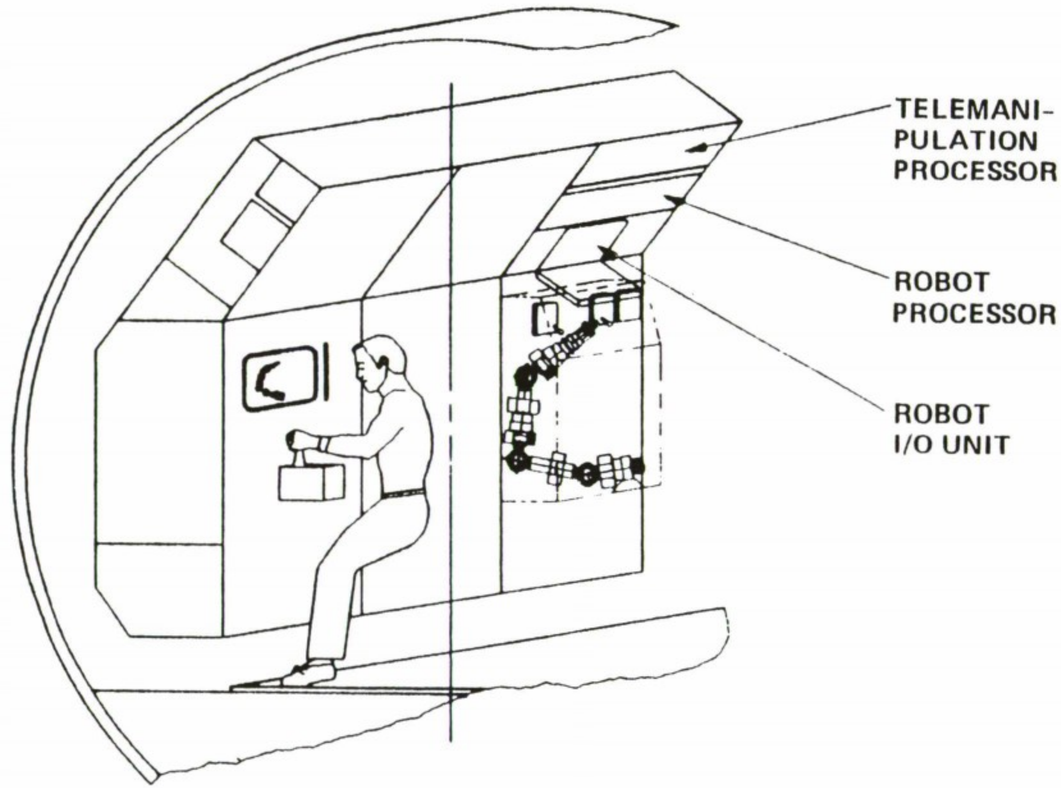
TRIIFEX

TELEROBOTIC INTELLIGENT INTERFACE FLIGHT EXPERIMENT

OAST — FLIGHT PROJECTS DIVISION



MOCK-UP OF TRIIFEX HARDWARE ON SPACELAB D-2 MISSION

CFMFE

CRYOGENIC FLUID MGMT FLIGHT EXP.

OAST — FLIGHT PROJECTS DIVISION

OBJECTIVES:

- DEVELOP TECHNOLOGY REQUIRED FOR EFFICIENT STORAGE, SUPPLY & TRANSFER OF SUBCRITICAL CRYOGENIC LIQUIDS IN LOW-GRAVITY SPACE ENVIRONMENT
- FLIGHT VALIDATE NUMERICAL MODELS OF THE PHYSICS INVOLVED

STATUS:

- CONTRACTOR FEASIBILITY STUDIES CURRENTLY UNDER WAY
- 1992 NEW START PROPOSED

LEAD CENTER CONTACT:

- E. PAT SYMONS
  LEWIS RESEARCH CENTER
  PHONE NO. (216) 433-2853

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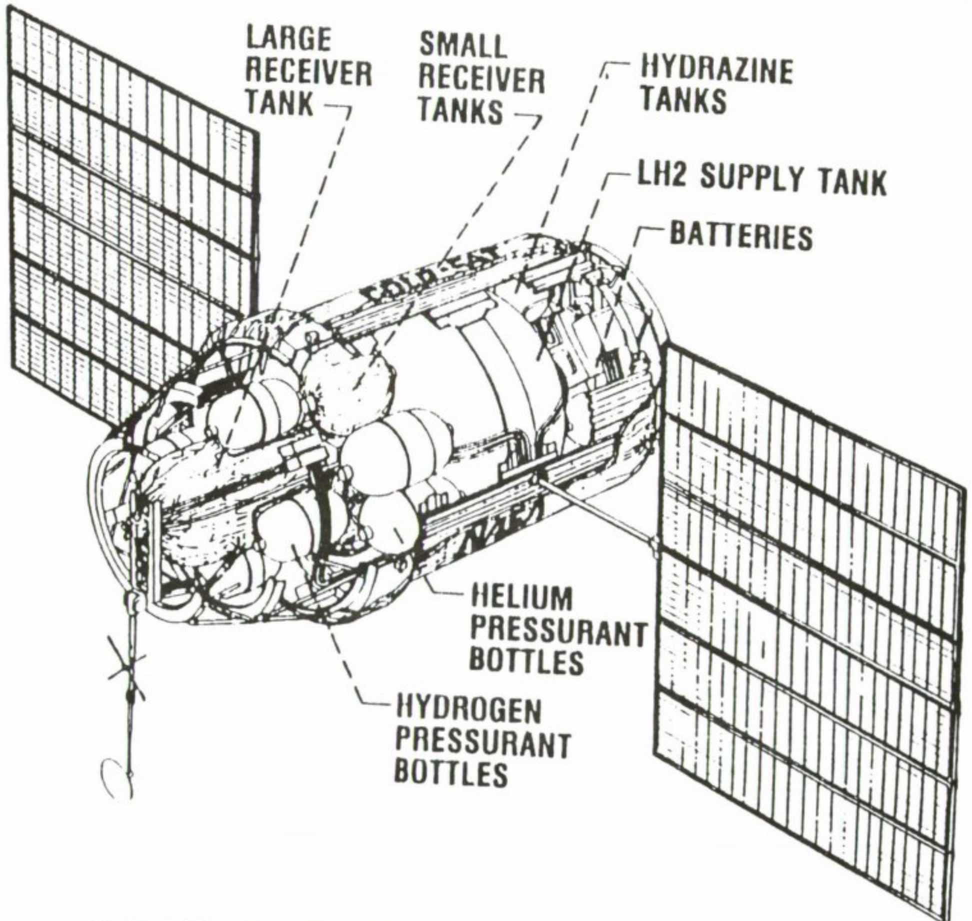
CFMFE

CRYOGENIC FLUID MGMT FLIGHT EXP.

OAST FLIGHT PROJECTS DIVISION



COLD-SAT SPACECRAFT

AIAA/OAST LM14 7/25/88

INDUSTRY/UNIVERSITY IN-SPACE TECHNOLOGY EXPERIMENTS

OUT-REACH PROGRAM

OBJECTIVES:

- PROVIDE FOR IN-SPACE FLIGHT RESEARCH EVALUATION & VALIDATION OF ADVANCED SPACE TECHNOLOGIES FOR THE INDUSTRY & UNIVERSITY COMMUNITY

STATUS:

- 7 MAJOR THEME AREAS
- 41 FLIGHT EXPERIMENT PROPOSALS SELECTED

PROGRAM CONTACT:

JON PYLE
NASA HEADQUARTERS
PHONE NO. (202) 453-2831

IN-REACH PROGRAM

OBJECTIVES:

- EXPAND THE NASA IN-SPACE R&T PROGRAM BY THE PROMOTION OF SPACE FLIGHT EXPERIMENTS WITHIN THE NASA CENTERS
- FORMALIZE THE PROCESS FOR SELECTION OF CANDIDATE EXPERIMENTS IN THE SPACE STATION ERA

STATUS:

- 58 EXPERIMENT PROPOSALS SUBMITTED
- 7 FLIGHT EXPERIMENTS SELECTED FOR DEFINITION & DEVELOPMENT

PROGRAM CONTACT:

JON PYLE
NASA HEADQUARTERS
PHONE NO. (202) 453-2831

AFE
AEROASSIST FLIGHT EXPERIMENT

OAST — FLIGHT PROJECTS DIVISION

OBJECTIVE:

- INVESTIGATE CRITICAL VEHICLE DESIGN & ENVIRONMENTAL TECHNOLOGIES APPLICABLE TO THE DESIGN OF AEROASSISTED SPACE TRANSFER VEHICLES

STATUS:

- PHASE B DEFINITION COMPLETE
- EXPERIMENT/INSTRUMENT COMPLEMENT ESTABLISHED
- PRELIMINARY DESIGN INITIATED

LEAD CENTER CONTACT:

- LEON B. ALLEN
  MARSHALL SPACE FLIGHT CENTER
  PHONE NO. (205) 544-1917

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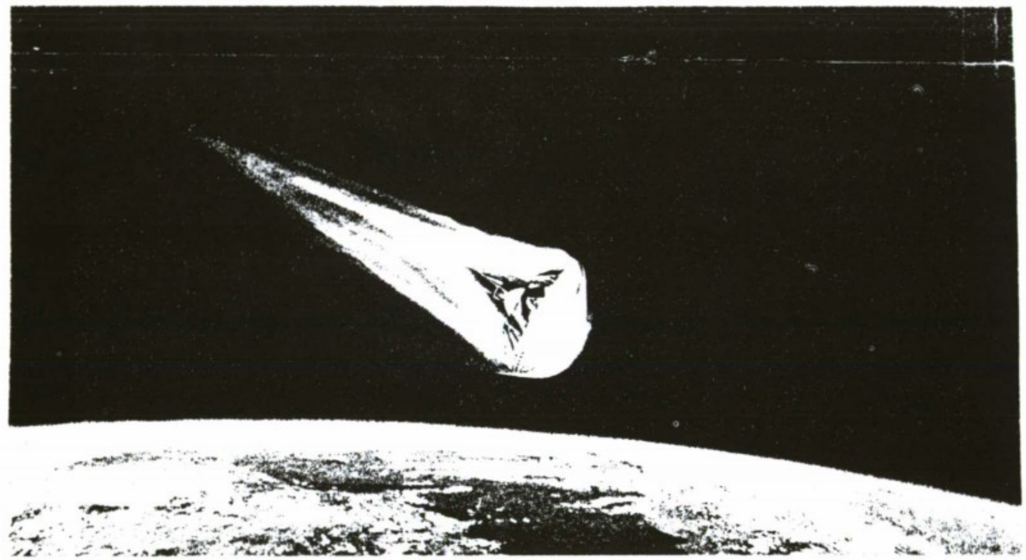
AFE

AEROASSIST FLIGHT EXPERIMENT

OAST — FLIGHT PROJECTS DIVISION



SCIENCE & TECHNOLOGY OBJECTIVES:

- UNDERSTAND RADIATIVE HEATING WHERE THE SHOCK LAYER IN CHEMICAL NON-EQUILIBRIUM
- DETERMINE CATALYTIC EFFICIENCY WHERE NITROGEN IS MOSTLY DISASSOCIATED & SOME IONIZATION IS PRESENT IN THE SHOCK LAYER
- EVALUATE ADVANCED THERMAL PROTECTION SYSTEM MATERIALS
- VERIFY PREDICTIVE TECHNIQUES FOR THE BASE FLOW & WAKE REGION
- ASSESS CONTROL ISSUES RELATED TO ATMOSPHERIC VARIABLES WHICH AN ASTV MIGHT ENCOUNTER
- VERIFY COMPUTATIONAL CODES FOR PREDICTION OF ASTV HEATING ENVIRONMENT & AERODYNAMIC PERFORMANCE

AIAA/OAST-L13 8/22/88

SUMMARY

- LONG & SUCCESSFUL HISTORY IN THE CONDUCT OF SPACE FLIGHT TECHNOLOGY EXPERIMENTS
- PROGRAM IS BEING EXPANDED TO EMPHASIZE THE DEVELOPMENT OF ADVANCED SPACE FLIGHT TECHNOLOGIES
- OAST PLANS TO PROVIDE ACCESS TO SPACE FOR THE AEROSPACE TECHNOLOGY COMMUNITY (NASA, DOD, INDUSTRY & UNIVERSITIES)

IN-SPACE TECHNOLOGY EXPERIMENTS

IN-REACH & OUT-REACH PROGRAMS

A
PROGRAM
OVERVIEW
BY
JON S. PYLE

OAST
FLIGHT PROJECTS DIVISION

AIAA/OAST P-1 7/29/88

IN-SPACE TECHNOLOGY EXPERIMENTS

OAST — FLIGHT PROJECTS DIVISION

IN-REACH & OUT-REACH PROGRAMS

- FORMALIZED PROCESS OF IDENTIFYING ADVANCED SPACE TECHNOLOGIES
  - TECHNOLOGIES MUST BE FULLY DEVELOPED ON GROUND
  - REQUIRES SPACE FLIGHT ENVIRONMENT FOR VALIDATION OR VERIFICATION
- PROGRAMS INCLUDE:
  - EXPERIMENT DEFINITION
  - HARDWARE DEVELOPMENT
  - EXPERIMENT INTEGRATION
  - FLIGHT SUPPORT
  - REPORTING

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IN-SPACE TECHNOLOGY EXPERIMENTS

OBJECTIVES

OAST — FLIGHT PROJECTS DIVISION

- PROVIDE FOR IN-SPACE FLIGHT RESEARCH EVALUATION & VALIDATION OF ADVANCED SPACE TECHNOLOGIES

    OUT-REACH PROGRAM

    - INDUSTRY/UNIVERSITY FLIGHT TECHNOLOGY EXPERIMENTS

    IN-REACH PROGRAM

    - NASA FLIGHT TECHNOLOGY EXPERIMENTS

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IN-REACH

NASA IN-SPACE TECHNOLOGY EXP.

OAST — FLIGHT PROJECTS DIVISION

- CENTERS REPRESENTED:

  ARC, GSFC, JPL, JSC, LaRC, LeRC, MSFC

  - 58 PROPOSALS SUBMITTED
  - 7 PROPOSALS SELECTED

- FLIGHT EXPERIMENT DEFINITION:
  - DEBRIS COLLISION SENSOR
  - SPACE STATION STRUCTURAL CHARACTERIZATION
  - LASER COMMUNICATION
  - LASER SENSOR
  - CONTAMINATION SENSOR
  - EXPOSURE OF THIN-FOIL MIRRORS

- FLIGHT EXPERIMENT DEVELOPMENT
  - THERMAL ENERGY STORAGE MATERIALS TECHNOLOGY

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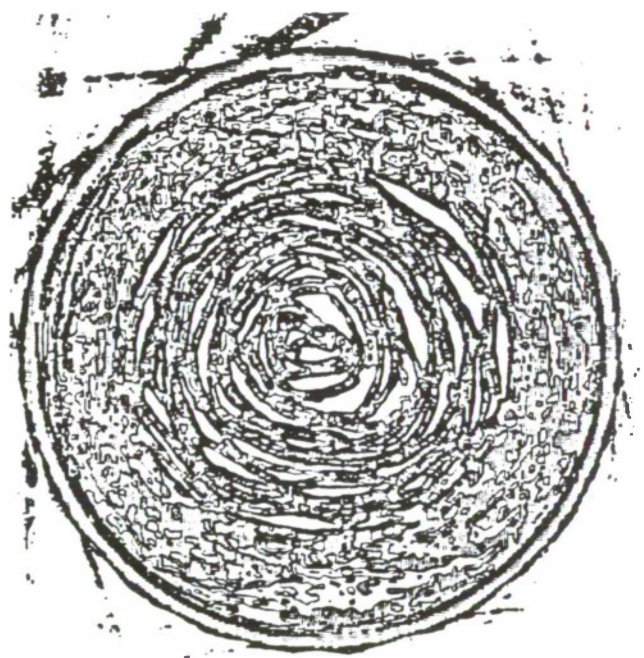
IN-REACH

FLIGHT EXPERIMENT DEVELOPMENT

OAST — FLIGHT PROJECTS DIVISION

THERMAL ENERGY STORAGE (TES) MATERIALS TECHNOLOGY



COMPUTER ENHANCED SCAN OF TES CANISTER CROSS-SECTION

CONCEPT:

- IN-SPACE THERMAL CYCLING OF A VARIETY OF PHASE CHANGE TES MATERIALS (VARING TEMPERATURE RANGES) TO UNDERSTAND VOID CHARACTERIZATION IN MICRO-G

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IN-REACH

FLIGHT EXPERIMENT DEVELOPMENT

OAST — FLIGHT PROJECTS DIVISION

THERMAL ENERGY STORAGE (TES) MATERIALS TECHNOLOGY

OBJECTIVES:

- IDENTIFY VOID LOCATION, VOID SIZE & MELT/FREEZE PATTERNS FOR VARIOUS TEMPERATURE RANGE TES MATERIALS UNDER MICRO-GRAVITY CONDITIONS
- VERIFY ANALYTICAL & GROUND EXPERIMENTAL PREDICTED BEHAVIOR OF TES MATERIALS SUBJECTED TO THE MICRO-GRAVITY ENVIRONMENT

BENEFITS/PAYOFFS:

- CRITICAL TO DESIGN OF ADVANCED, LONGER LIFE, HIGHLY RELIABLE INTEGRALTHERMAL STORAGE HEAT RECEIVERS
- SIGNIFICANT REDUCTION IN WEIGHT POSSIBLE OVER PHOTOVOLTAIC SYSTEM

LEAD CENTER CONTACT:

- DR. LYNN ANDERSON
  LEWIS RESEARCH CENTER
  (216) 433-2874

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OUT-REACH

INDUSTRY/UNIVERSITY IN-SPACE TECHNOLOGY EXPERIMENTS

- **PARTICIPATION:**
  - 231 PROPOSALS SUBMITTED (91 UNIVERSITY & 140 INDUSTRY)

- **36 FLIGHT EXPERIMENT DEFINITION STUDIES:**
  - 5 SPACE STRUCTURES
  - 7 FLUID MANAGEMENT
  - 3 INFORMATION SYSTEMS
  - 5 ENERGY SYSTEMS & THERMAL MANAGEMENT
  - 2 SPACE ENVIRONMENTAL EFFECTS
  - 10 IN-SPACE OPERATIONS
  - 4 AUTOMATION & ROBOTICS

- **5 FLIGHT EXPERIMENT HARDWARE DEVELOPMENTS:**
  - HEAT PIPE THERMAL PERFORMANCE & FLUID BEHAVIOR
  - TANK PRESSURE CONTROL
  - INVESTIGATION OF SPACECRAFT GLOW
  - MID-DECK ZERO-GRAVITY DYNAMICS EXPERIMENT
  - EMULSION CHAMBER TECHNOLOGY

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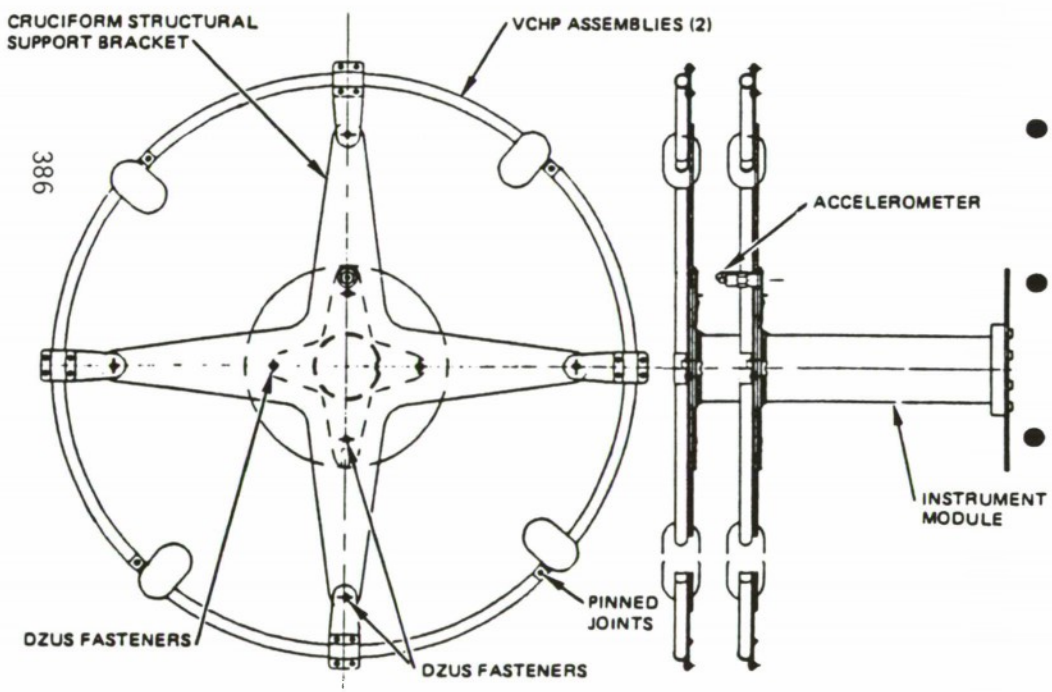
OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

HEAT PIPE PERFORMANCE & WORKING FLUID BEHAVIOR



CONCEPT:

- SPACE SHUTTLE MID-DECK LOCKER OR COMPLEX SELF-CONTAINED PAYLOAD
- TWO SETS OF HEAT PIPES (4 EACH) MOUNTED ON A CRUCIFORM STRUCTURE
- ARTIFICIAL ACCELERATION LEVELS (VARIABLE G) APPLIED TO HEAT PIPES BY CONTROLLED SPINNING

AIAA/OAST P-5a 9/1/88

OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

OAST FLIGHT PROJECTS DIVISION

HEAT PIPE PERFORMANCE & WORKING FLUID BEHAVIOR

OBJECTIVES:

- STUDY EFFECTS OF MICRO-GRAVITY ON WORKING FLUIDS IN HEAT PIPES
- DETERMINE RECOVERY RATES FOR DEPRIMED VARIABLE CONDUCTANCE HEAT PIPES IN 0-G
- VALIDATE ANALYTICAL MODELS & UPGRADE GROUND TEST TECHNIQUES

BENEFITS/PAYOFFS:

- SPACECRAFT LIQUID INVENTORIES COULD BE REDUCED THROUGH BETTER UNDERSTANDING OF 0-G FLUID BEHAVIOR
- IMPROVE POWER SYSTEM HEAT DISIATION & REDUCE ADVANCED SPACECRAFT SYSTEM DESIGN RISKS

LEAD CENTER CONTACT:

- DON FRIEDMAN
  GODDARD SPACE FLIGHT CENTER
  (301) 286-6242

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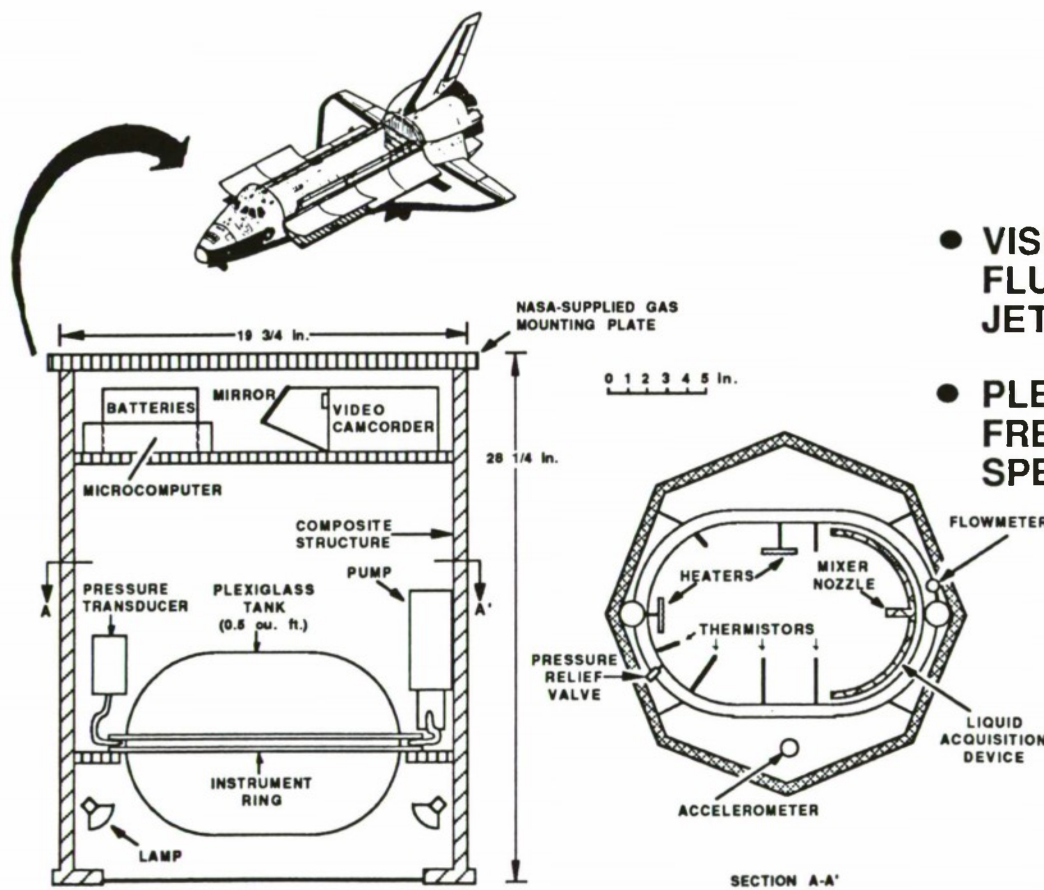
OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

OAST FLIGHT PROJECTS

TANK PRESSURE CONTROL EXPERIMENT



CONCEPT:

- VISUAL & THERMAL EVALUATION OF FLUID MIXING BY MEANS OF A JET INDUCED FLOW
- PLEXIGAS CANNISTER USING LIQUID FREON MOUNTED IN A GET AWAY SPECIAL (GAS) PAYLOAD (MANIFESTED 7/90)

AIAA/OAST P-5b 9/1/88

OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

OAST — FLIGHT PROJECTS DIVISION

TANK PRESSURE CONTROL EXPERIMENT

OBJECTIVES:

- DETERMINE THERMAL STRATIFICATION OF FLUIDS IN 0-G
- STUDY EFFECTIVENESS OF JET INDUCED MIXING
- VALIDATE OR UPGRADE EXISTING ANALYTICAL MODELS

BENEFITS/PAYOFFS:

- REDUCES TANK OVERPRESSURE RISKS CAUSED BY HIGH THERMAL GRADIENTS IN LIQUIDS
- PROVIDES BETTER DESIGN TECHNIQUES FOR FUTURE SPACECRAFT SYSTEMS

LEAD CENTER CONTACT:

- DR. LYNN ANDERSON
LEWIS RESEARCH CENTER
(216) 433-2874

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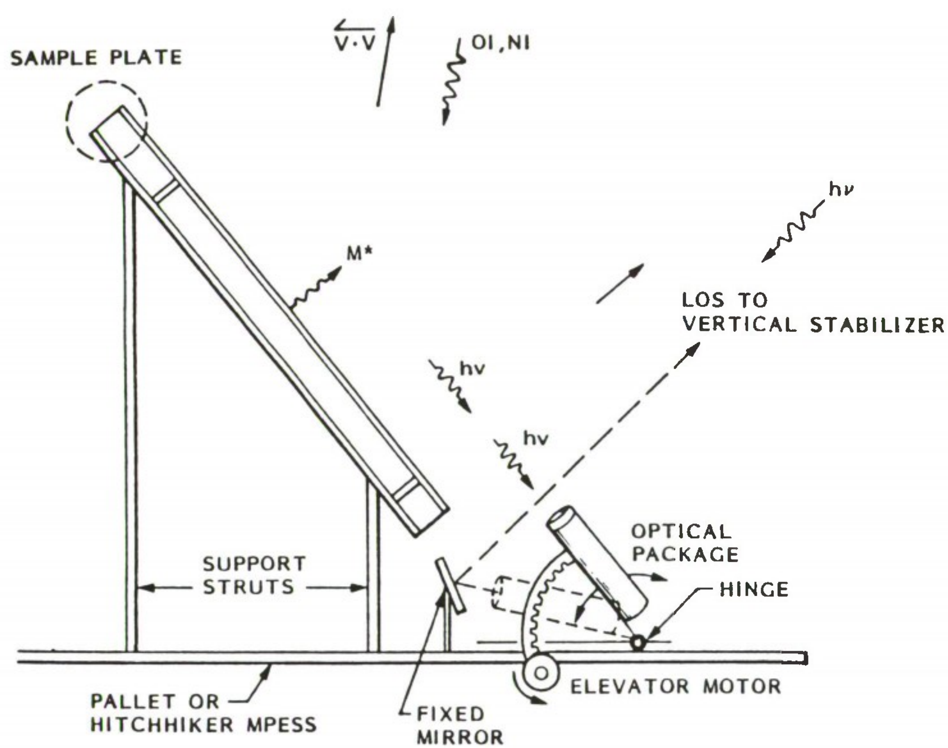
OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

INVESTIGATION OF SPACECRAFT GLOW



CONCEPT:

- PLATE WITH MATERIAL SAMPLES MOUNTED TOWARD RAM (NORMAL INCIDENCE) DIRECTION
- OPTICAL MEASUREMENTS USED TO CHARACTERIZE THE GLOW
- OBTAIN MEASUREMENTS OF GLOW ABOVE MATERIAL SURFACE OVER TEMPERATURE RANGE & SPECTRAL REGIONS

OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

INVESTIGATION OF SPACECRAFT GLOW

OBJECTIVES:

- MEASURE THE INTENSITY, SPATIAL DISTRIBUTION & SPECTRUM OF SPACE GLOW
- DETERMINE THE GLOW INTENSITY AS A FUNCTION OF SURFACE TEMPERATURE & MATERIALS
- IDENTIFY MECHANISMS PRODUCING GLOW & APPROACHES TO MINIMIZE ITS EFFECTS

BENEFITS/PAYOFFS:

- ELIMINATE INTERFERRENCE OF GLOW ON SPACE FLIGHT EXPERIMENTS (SUCH AS OPTICS)
- MAY PROVIDE TECHNIQUES FOR SPACECRAFT DETECTION & IDENTIFICATION

LEAD CENTER CONTACT:

- KEITH HENDERSON
  JOHNSON SPACE CENTER
  (713) 282-1807

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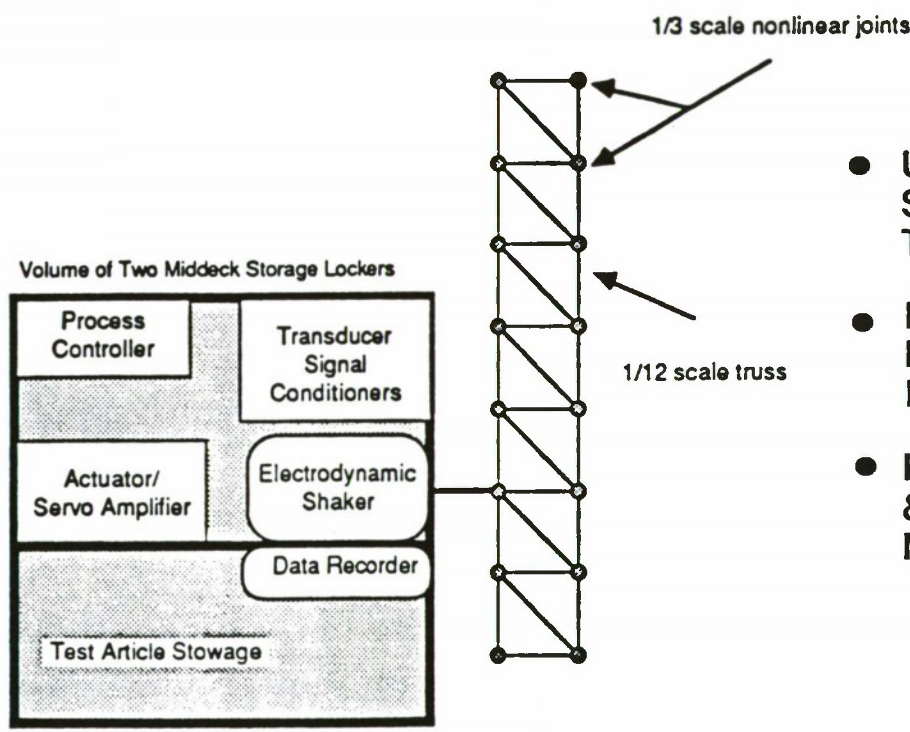
OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

MID-DECK ZERO-GRAVITY DYNAMICS EXPERIMENT



CONCEPT:

- USES SKEWED-SCALE ERECTABLE STRUCTURE WITH SPACE STATION TYPE JOINTS
- ELECTRONICALLY CONTROLLED EXCITER DYNAMICS TO PROVIDE PREDICTABLE INTERACTION
- REUSABLE EXCITER/CONTROLLER & DATA RETREIVAL SYSTEM IN MID-DECK LOCKERS

AIAA/OAST P-5d 9/1/88

OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

O-A-S-T — FLIGHT PROJECTS DIVISION

MID-DECK ZERO-GRAVITY DYNAMICS EXPERIMENT

OBJECTIVES:

- INVESTIGATE DYNAMICS OF NONLINEAR SPACECRAFT SYSTEMS IN A MICRO-GRAVITY ENVIRONMENT
- PROVIDE LONG DURATION 0-G FLIGHT DATA TO CORRELATE WITH GROUND TEST RESULTS & ANALYTICAL PREDICTIONS

BENEFITS/PAYOFFS:

- REDUCE RISKS OF SPACECRAFT DESTABILIZATION DUE TO LIMITED UNDERSTANDING OF COMPLEX DYNAMIC INTERACTIONS
- IMPROVED DESIGN TECHNIQUES & GREATER RELIABILITY ALLOW REDUCTIONS IN SPACECRAFT WEIGHTS

LEAD CENTER CONTACT:

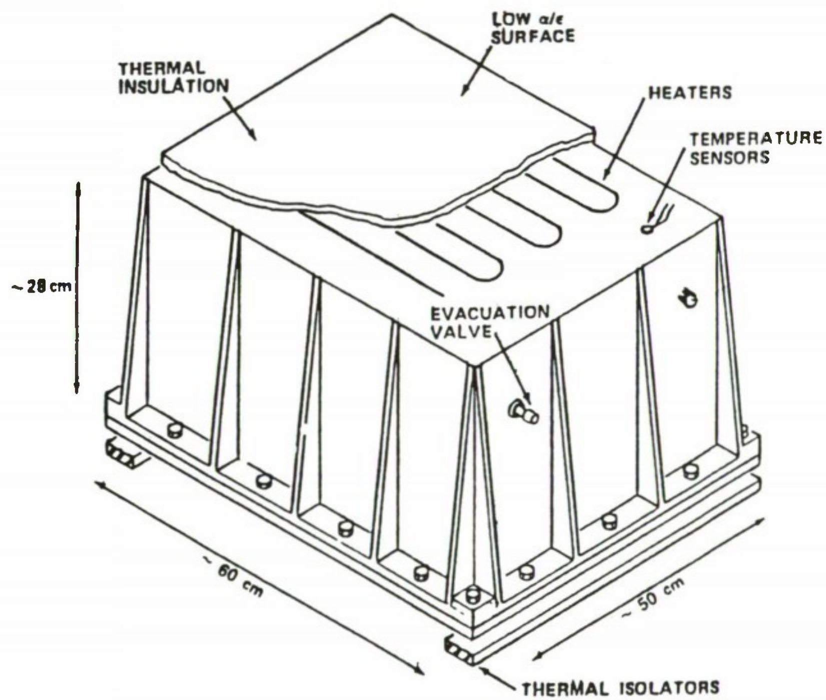
- LENWOOD CLARK
  LANGLEY RESEARCH CENTER
  (804) 865-4834

AIAA/OAST P-5d 9/1/88

OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

EMULSION CHAMBER TECHNOLOGY



CONCEPT:

- 300 LAYER NUCLEAR TRACK EMULSION IN SHIELDED HERMETIC ENCLOSURE
- LONG TERM EXPOSURE TO SPACE ENVIRONMENT IN SPACE SHUTTLE BAY

OUT-REACH

FLIGHT EXPERIMENT DEVELOPMENT

OAST — FLIGHT PROJECTS DIVISION

EMULSION CHAMBER TECHNOLOGY

OBJECTIVES:

- VALIDATION OF EMULSION CALORIMETER TO BE USED FOR HIGH ENERGY COSMIC RAY DETECTION
- STUDY OF SHIELDING TECHNIQUES FOR EMULSION CALORIMETERS
- VERIFY PREDICTED HIGH ENERGY PARTICLE DATA

BENEFITS/PAYOFFS:

- ENABLES EXTENSION OF COSMIC RAY COMPOSITION & NUCLEAR INTERACTION CHARATERISTICS
- POTENTIAL IMPROVEMENTS IN SHIELDING APPLICATIONS FOR FUTURE MANNED SPACECRAFT

LEAD CENTER CONTACT:

- JON HAUSSLER
  MARSHALL SPACE FLIGHT CENTER
  (205) 544-1762

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IN-REACH & OUT-REACH PROGRAMS

OAST FLIGHT PROJECTS

IN-SPACE TECHNOLOGY EXPERIMENTS

WORKSHOP

HYATT REGENCY HOTEL
ATLANTA, GA

DECEMBER 6, 7, 8, & 9, 1988

AIAA/OAST P-6 7/29/88

IN-REACH & OUT-REACH PROGRAMS

OAST — FLIGHT PROJECTS DIVISION

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP

WORKSHOP PURPOSE

- REVEIW OF CURRENT PROGRAMS & DISCUSSION OF FUTURE PLANS
- DESCRIPTION OF FLIGHT OPPORTUNITIES & INTEGRATION PROCESS
- IDENTIFICATION OF CRITICAL TECHNOLOGY NEEDS IN EACH THEME AREA

AIAA/OAST P-6a 7/29/88

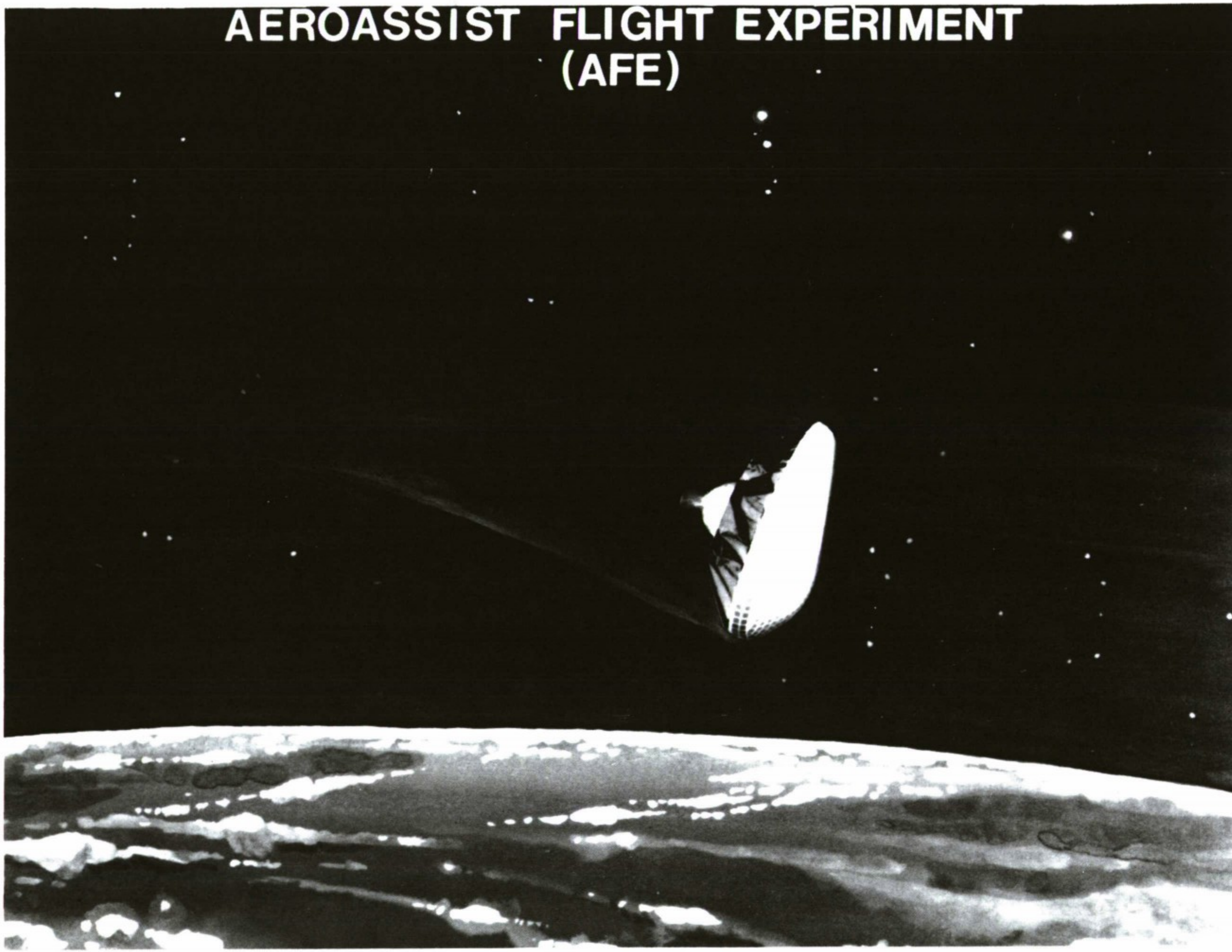
AEROASSIST FLIGHT EXPERIMENT (AFE)

AIAA / OAST CONFERENCE
ON CSTI AND PATHFINDER

TECHNOLOGY FOR FUTURE
NASA MISSIONS

SEPTEMBER 12-13, 1988

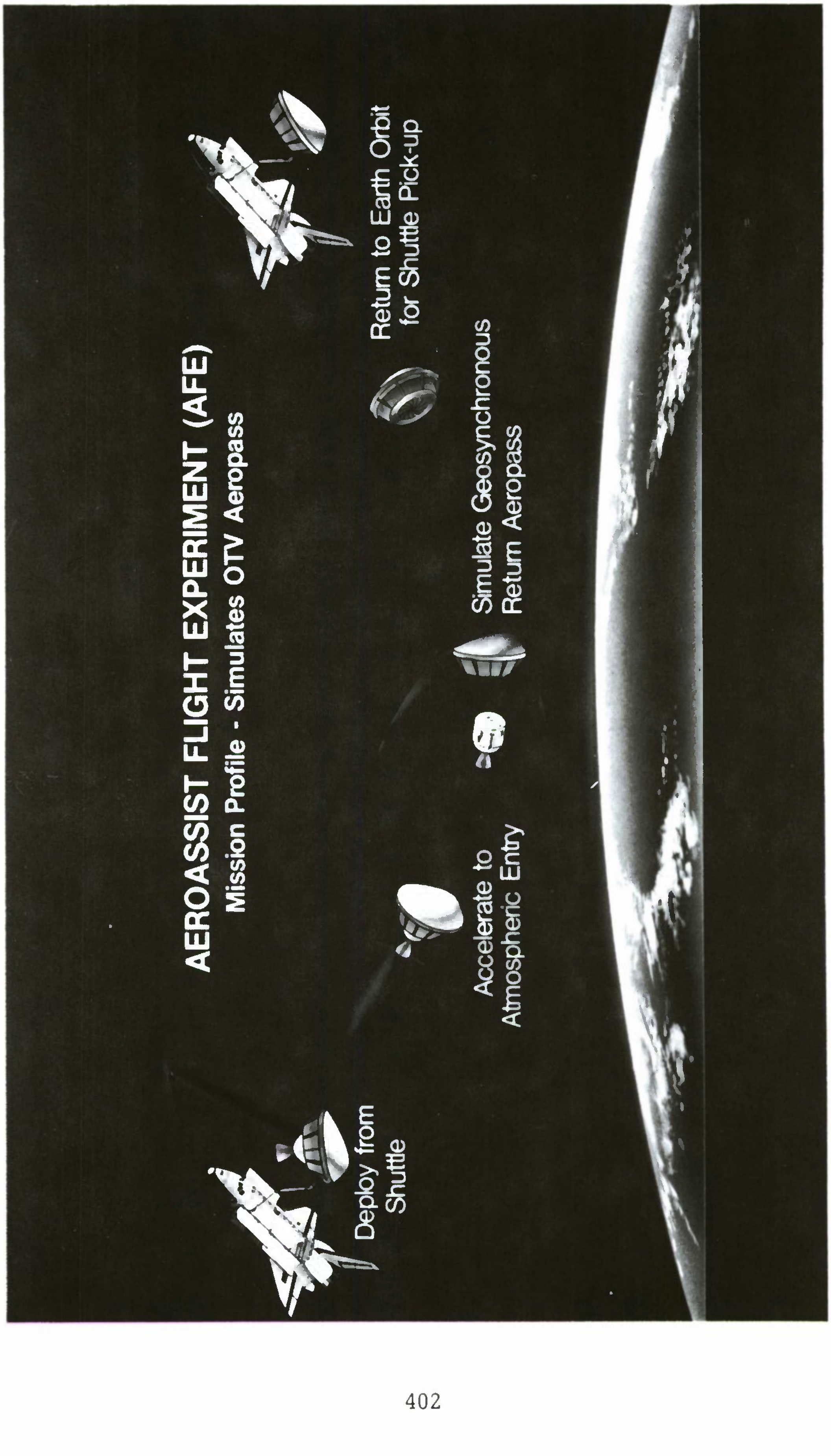
P. M. Siemers / NASA LaRC


AEROASSIST FLIGHT EXPERIMENT
(AFE)

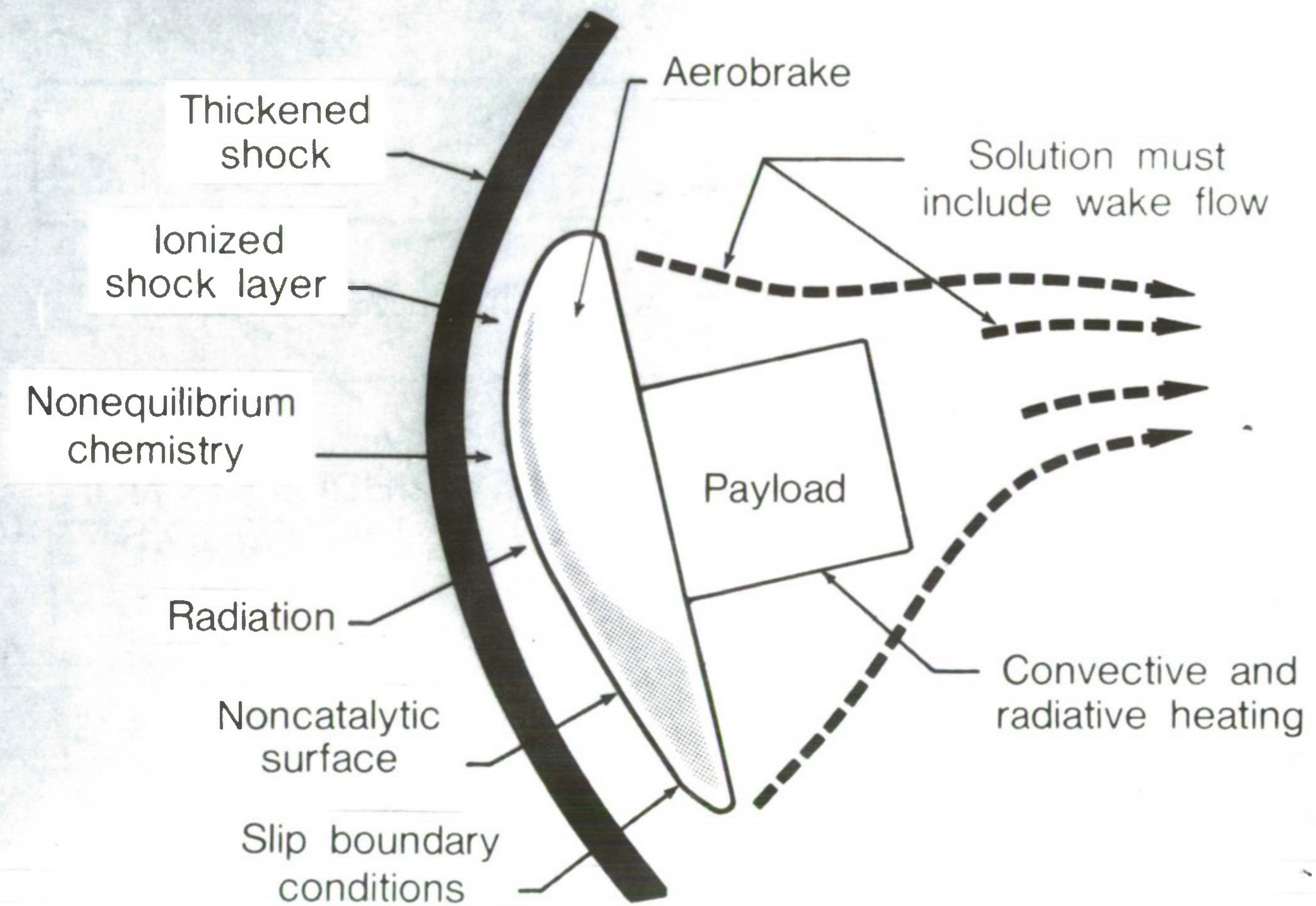
AEROASSIST FLIGHT EXPERIMENT

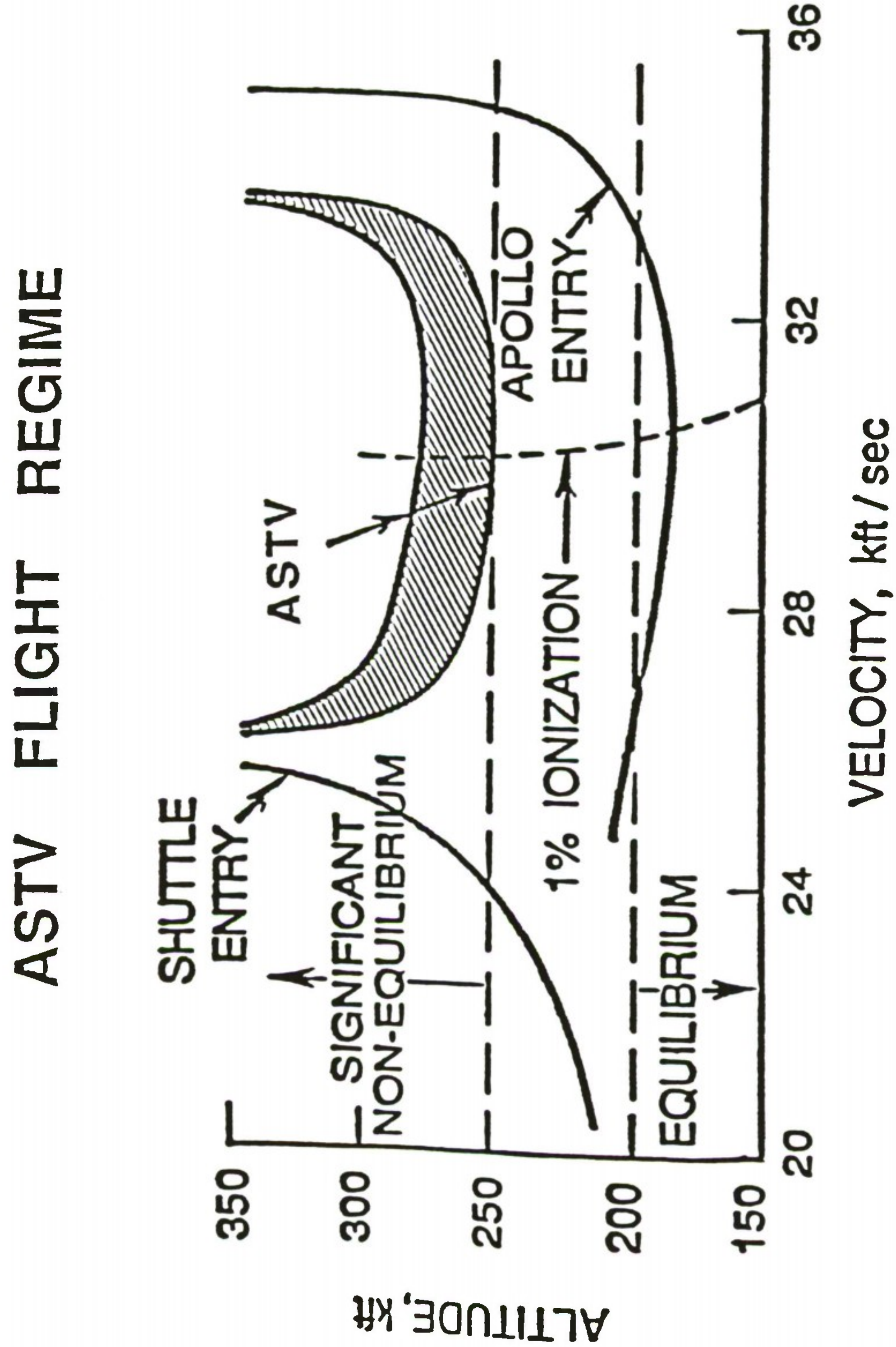
OBJECTIVE:

TO INVESTIGATE CRITICAL VEHICLE DESIGN AND ENVIRONMENTAL TECHNOLOGIES APPLICABLE TO THE DESIGN OF AEROASSISTED SPACE TRANSFER VEHICLES


AEROASSIST FLIGHT EXPERIMENT (AFE)
Mission Profile - Simulates OTV Aeropass
Deploy from Shuttle
Accelerate to Atmospheric Entry
Simulate Geosynchronous Return Aeropass
Return to Earth Orbit for Shuttle Pick-up

AOTV DESIGN / AFE SIMULATION CHALLENGES




ASTV FLIGHT REGIME
SHUTTLE ENTRY
SIGNIFICANT NON-EQUILIBRIUM
ASTV
APOLLO ENTRY
1% IONIZATION
EQUILIBRIUM
ALTITUDE, kft
350
300
250
200
150
20
24
28
32
36
VELOCITY, kft / sec

ASTV REQUIREMENTS SUMMARY

- INABILITY TO ESTABLISH DATA BASE REQUIRED IN GROUND FACILITIES ESTABLISHES NEED FOR COMPUTATIONAL CAPABILITIES WHICH MUST BE VERIFIED USING FLIGHT DATA
- EXISTING FLIGHT DATA NOT APPROPRIATE FOR ASTV
- AEROASSISTED TECHNOLOGY FLIGHT EXPERIMENT REQUIRED

AFE MISSION OBJECTIVES

OBTAIN DATA TO:

- RESOLVE RADIATIVE HEATING ISSUE
- DETERMINE WALL CATALYSIS EFFECTS
- DEVELOP / DEMONSTRATE TPS MATERIALS
- DEFINE WAKE FLOW, BASE HEATING
- ASSESS AERODYNAMICS AND CONTROL
- PROVIDE CFD CODE VERIFICATION DATA

AFE DESIGN / MISSION REQUIREMENTS

CONFIGURATION:

- SHOCK LAYER THICKNESS $\geq$ 7 INCHES
- BLUNT, RIGID FOREBODY
  - DIAMETER $\geq$ 12 FEET
- L/D 0.2 — 0.3
- ROLL CONTROLLED
- NON-ABLATIVE HEATSHIELD
- RECOVERABLE

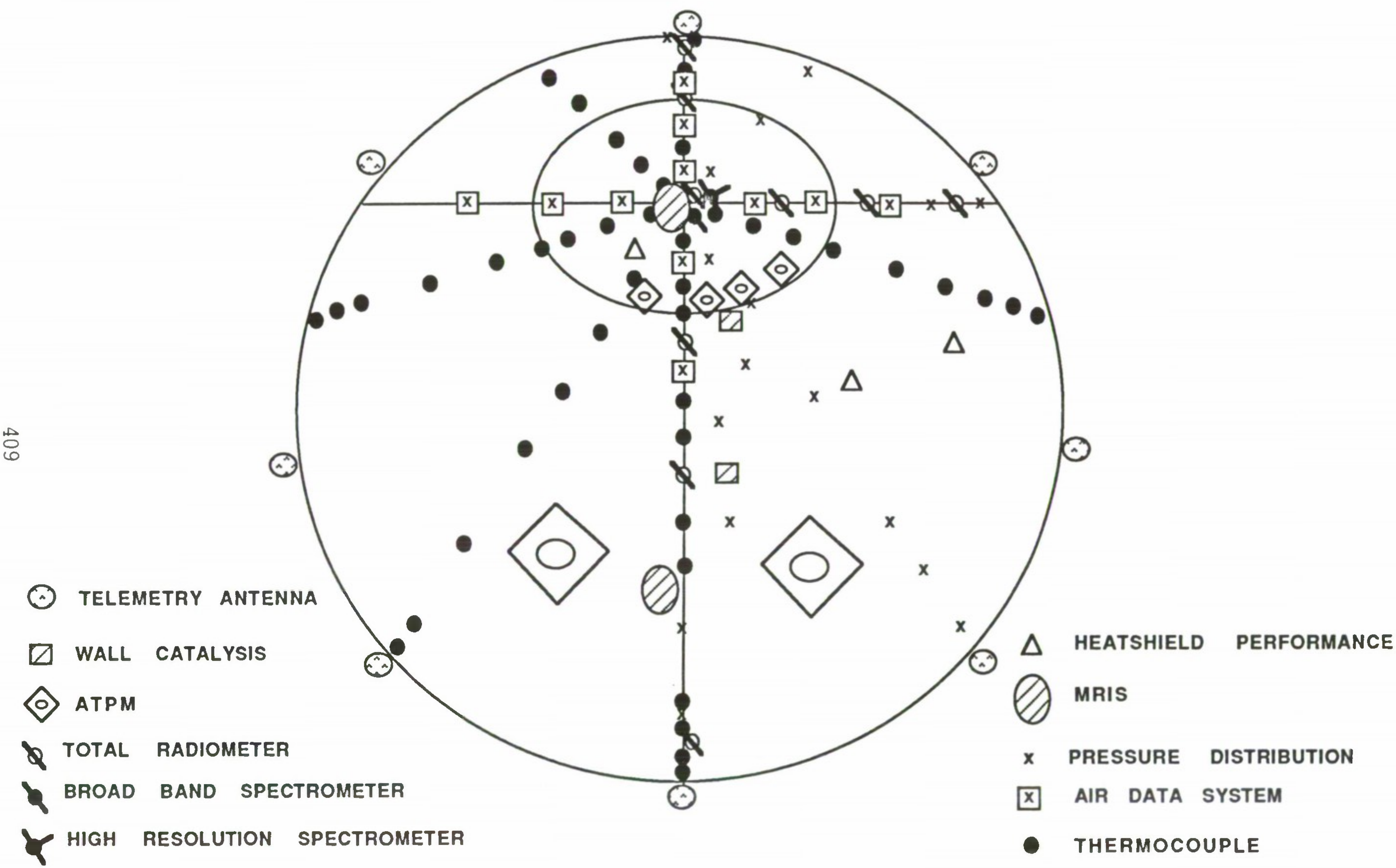
TRAJECTORY:

- ENTRY INTERFACE (400,000 FT) $\geq$ 33,800 FPS
- RELATIVE VELOCITY $\geq$ 31,660 FPS AT 279,000 FEET ALTITUDE
- PERIGEE = 250,000 $\pm$ 13,000 FEET
- QUIESCENT PERIOD PRIOR TO PERIGEE (30 SEC)

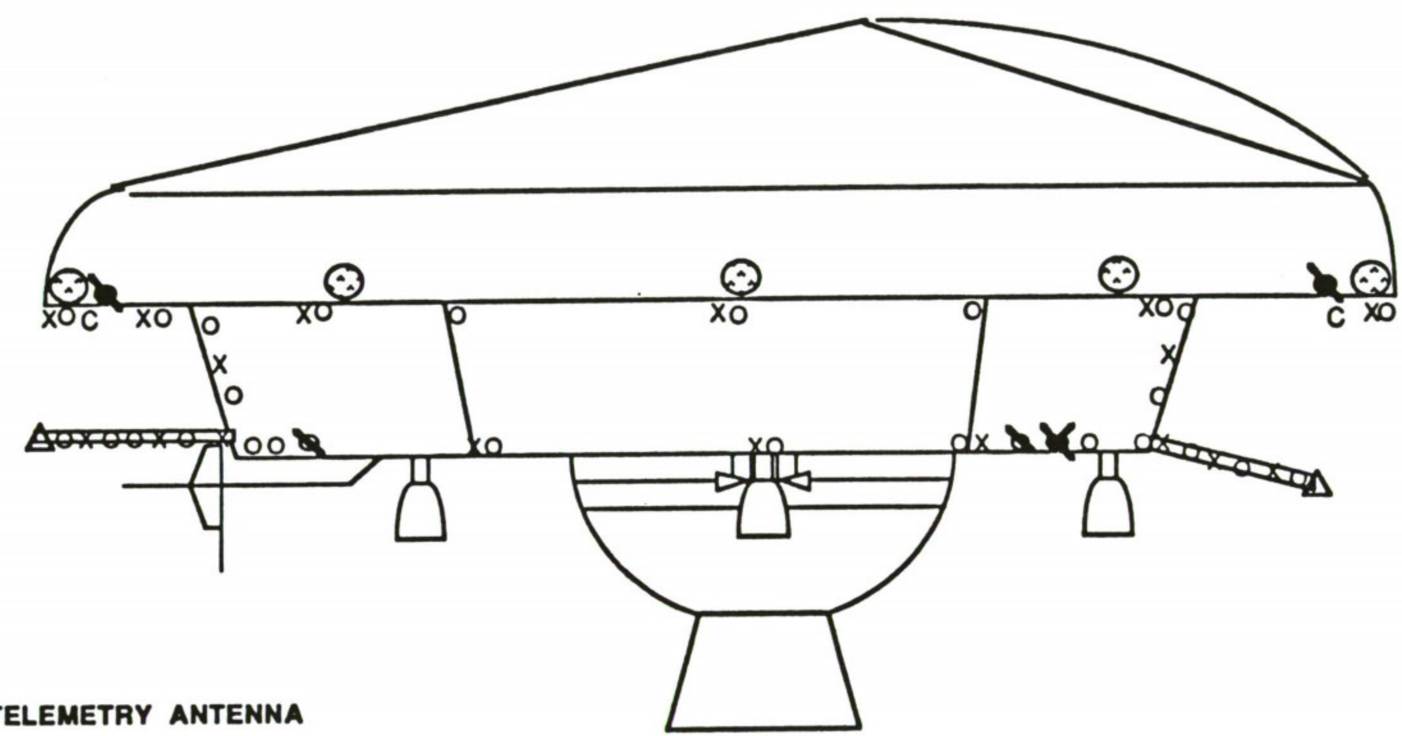
AFE INSTRUMENTATION

ASTV TECHNOLOGY ISSUE	AFE EXPERIMENT
SHOCK LAYER RADIATION	• RADIATIVE HEATING (RHE)
SURFACE CATALYSIS	• WALL CATALYSIS (WCE)
TPS MATERIALS	• HEAT SHIELD PERFORMANCE (HSP) • ALTERNATE THERMAL PROTECTION MATERIALS (ATPM)
WAKE FLOWS / HEATING	• BASE FLOW AND HEATING (BFHE) • AFTERBODY RADIOMETRY (ARE) • AFT FLOW IONIZATION (AFIE)
AERODYNAMICS / CONTROL	• AERODYNAMIC PERFORMANCE (APEX) • RAREFIED-FLOW AERODYNAMIC MEASUREMENT (RAME) • AIR DATA SYSTEM (PD/ADS)
COMPUTATIONAL FLUID DYNAMICS	• PRESSURE DISTRIBUTION (PD/ADS) • FOREBODY AEROTHERMAL CHARACTERIZATION (FACE) • MICROWAVE REFLECTOMETER IONIZATION SENSOR (MRIS) • RAREFIED-FLOW AERODYNAMIC MEASUREMENT (RAME)

FOREBODY INSTRUMENTATION

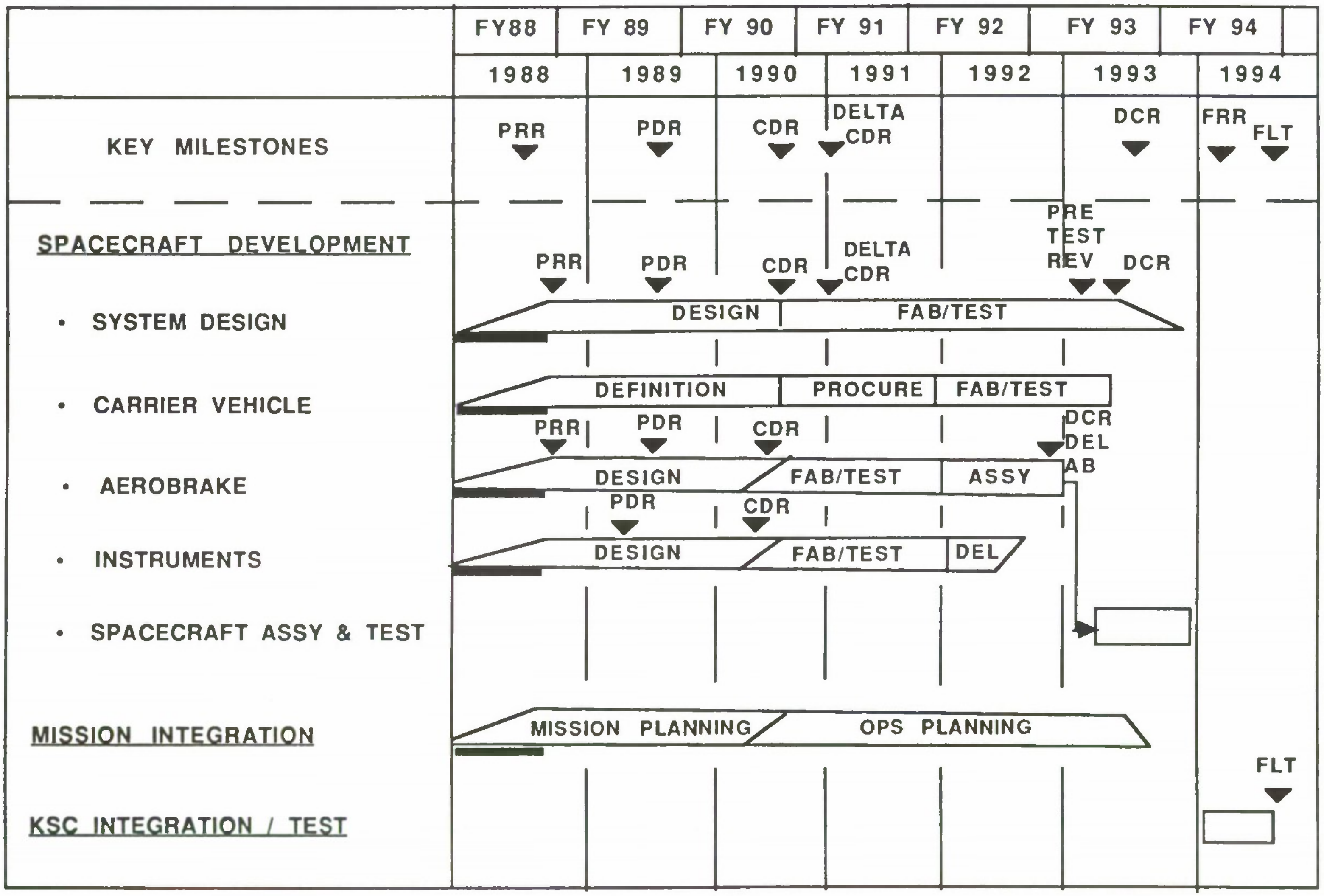


BASE REGION INSTRUMENTATION



AEROASSIST FLIGHT EXPERIMENT (AFE)

PROJECT SCHEDULE



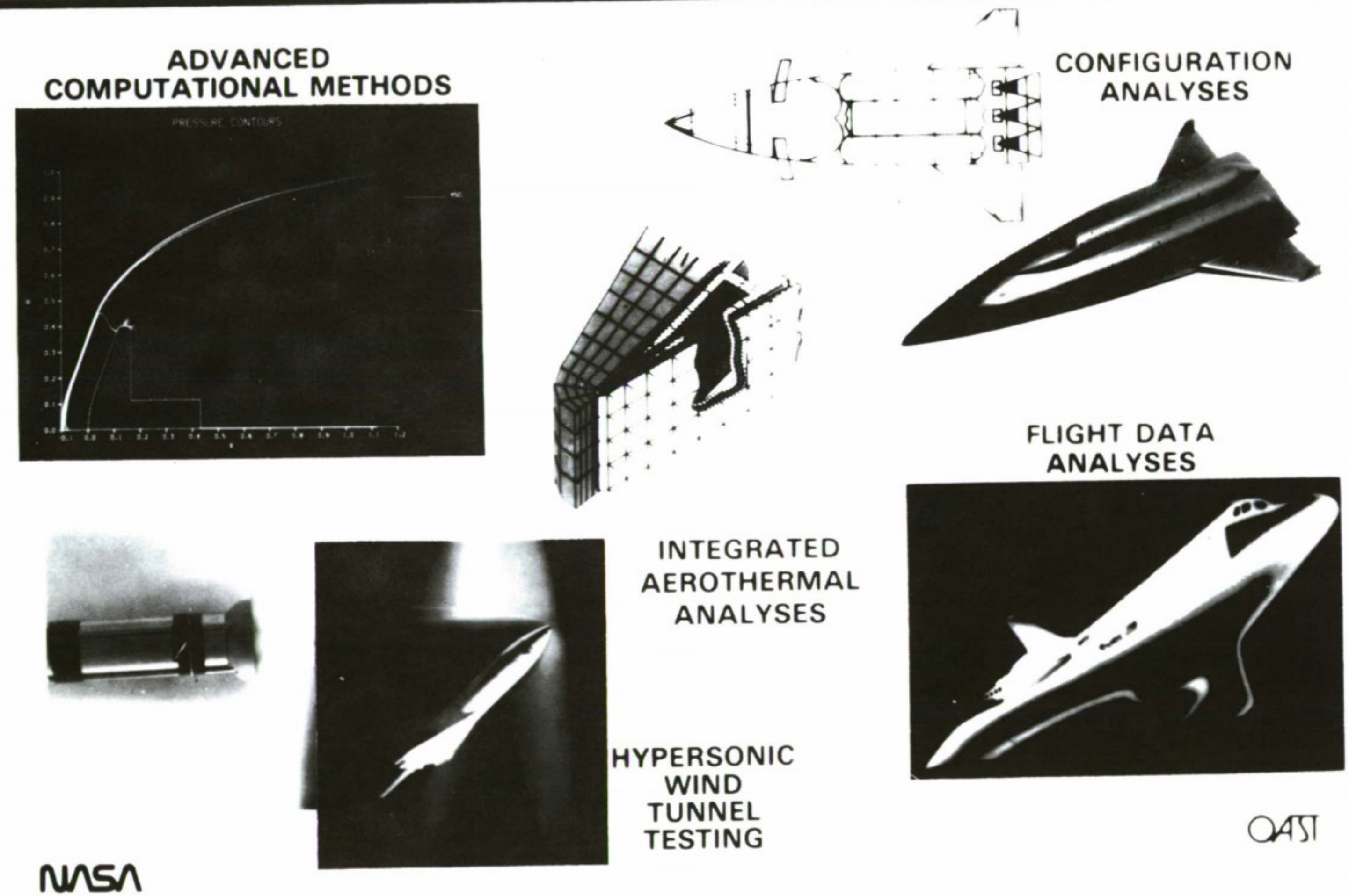
TECHNOLOGY FOR FUTURE NASA MISSIONS

AN AIAA/OAST CONFERENCE ON CSTI AND PATHFINDER

AEROTHERMODYNAMICS OVERVIEW

Dr. Randolph A. Graves, Jr.
Director, Aerodynamics Division

AEROTHERMODYNAMICS



HIGH ENERGY AEROBRAKING

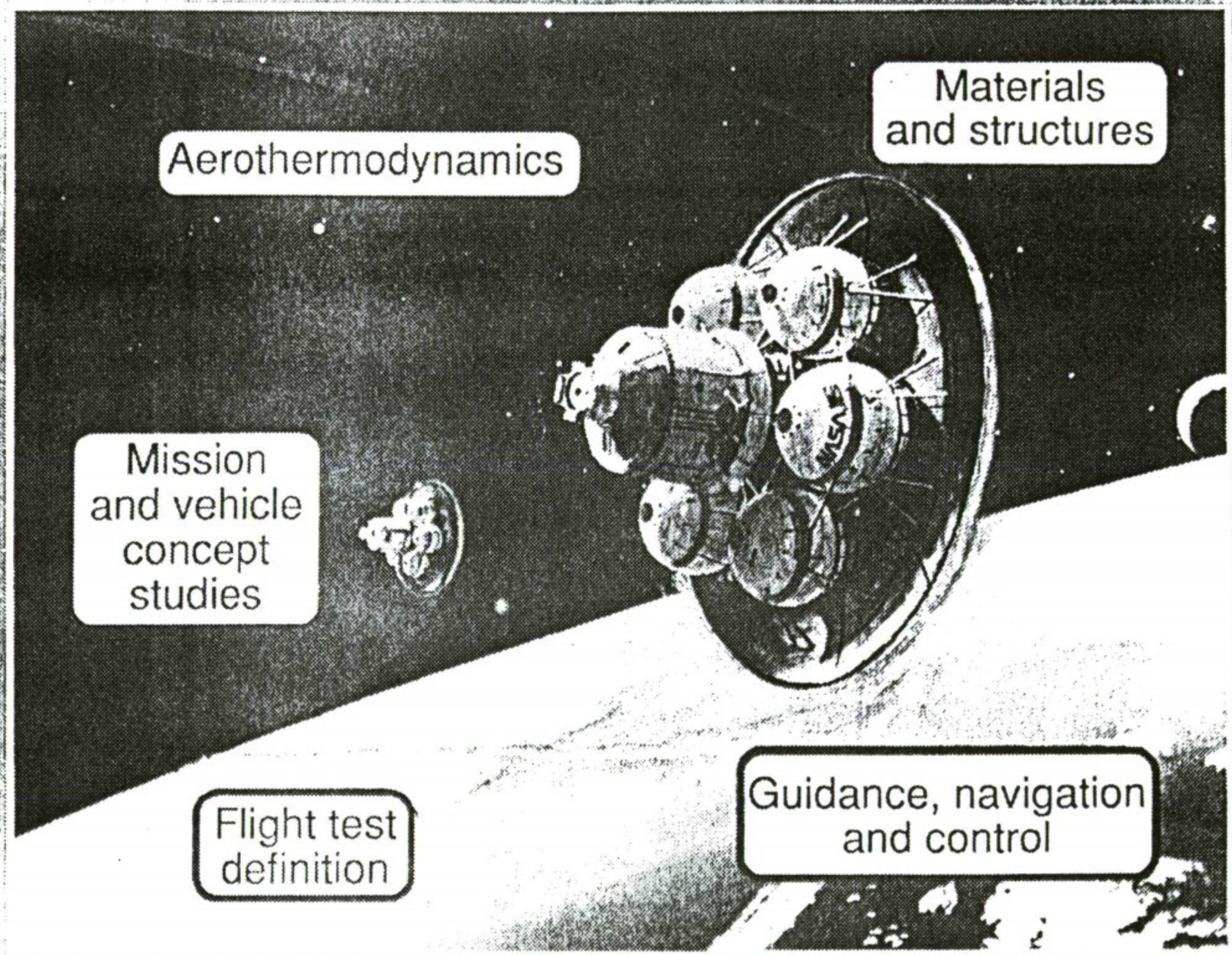
by

Gerald D. Walberg

Presented at the AIAA/OAST Conference on
Technology for Future NASA Missions

September 12-13, 1988

HIGH ENERGY AEROBRAKING



Approach: Analysis, ground and flight tests

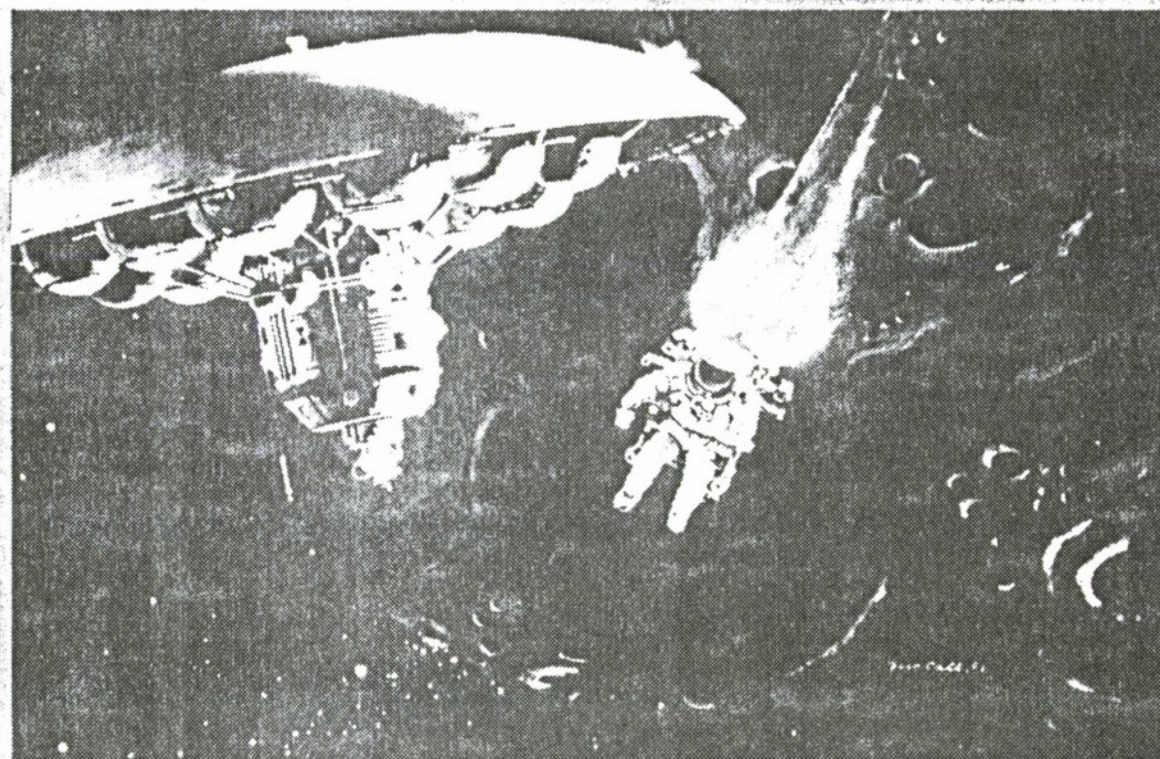
PROGRAM SCOPE

- Planetary and Earth-return aerocapture
- Planetary and Earth direct entry
- Aeromaneuvering and entry from planetary orbit

Manned and unmanned missions

NASA
L-88-8909

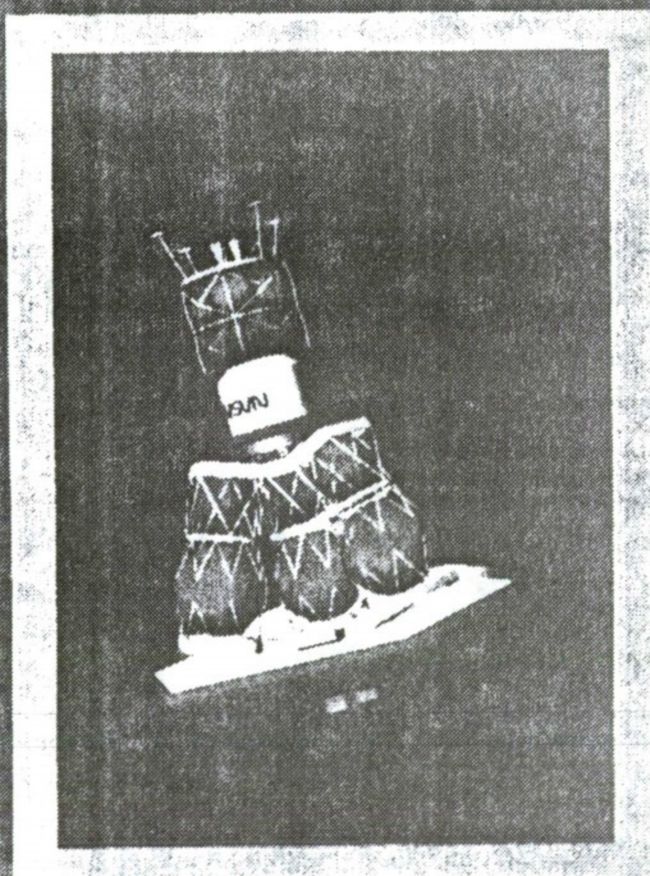
AEROBRAKING: ENABLING FOR LUNAR AND MARS MISSIONS

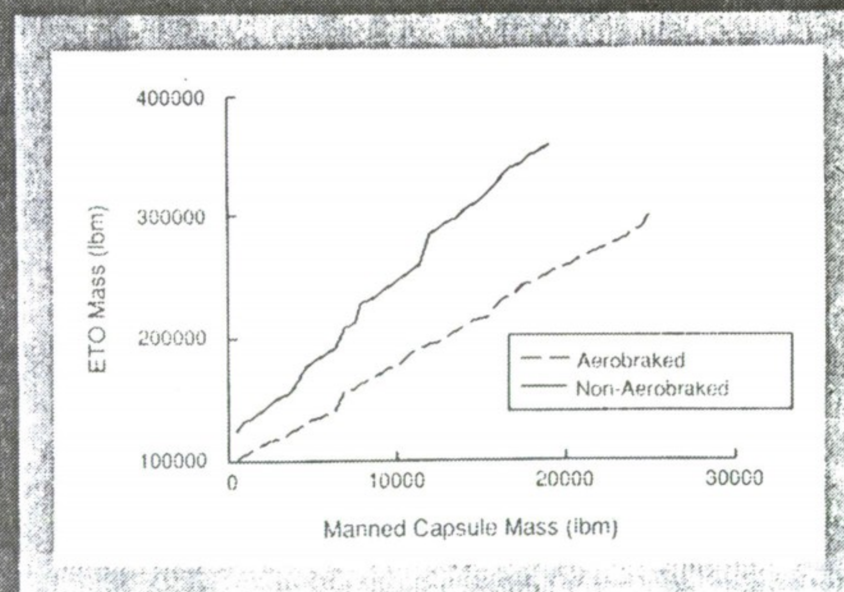


"Recommend demonstration projects in critical technologies supporting aerobraking for orbital transfer"
- National Commission on Space

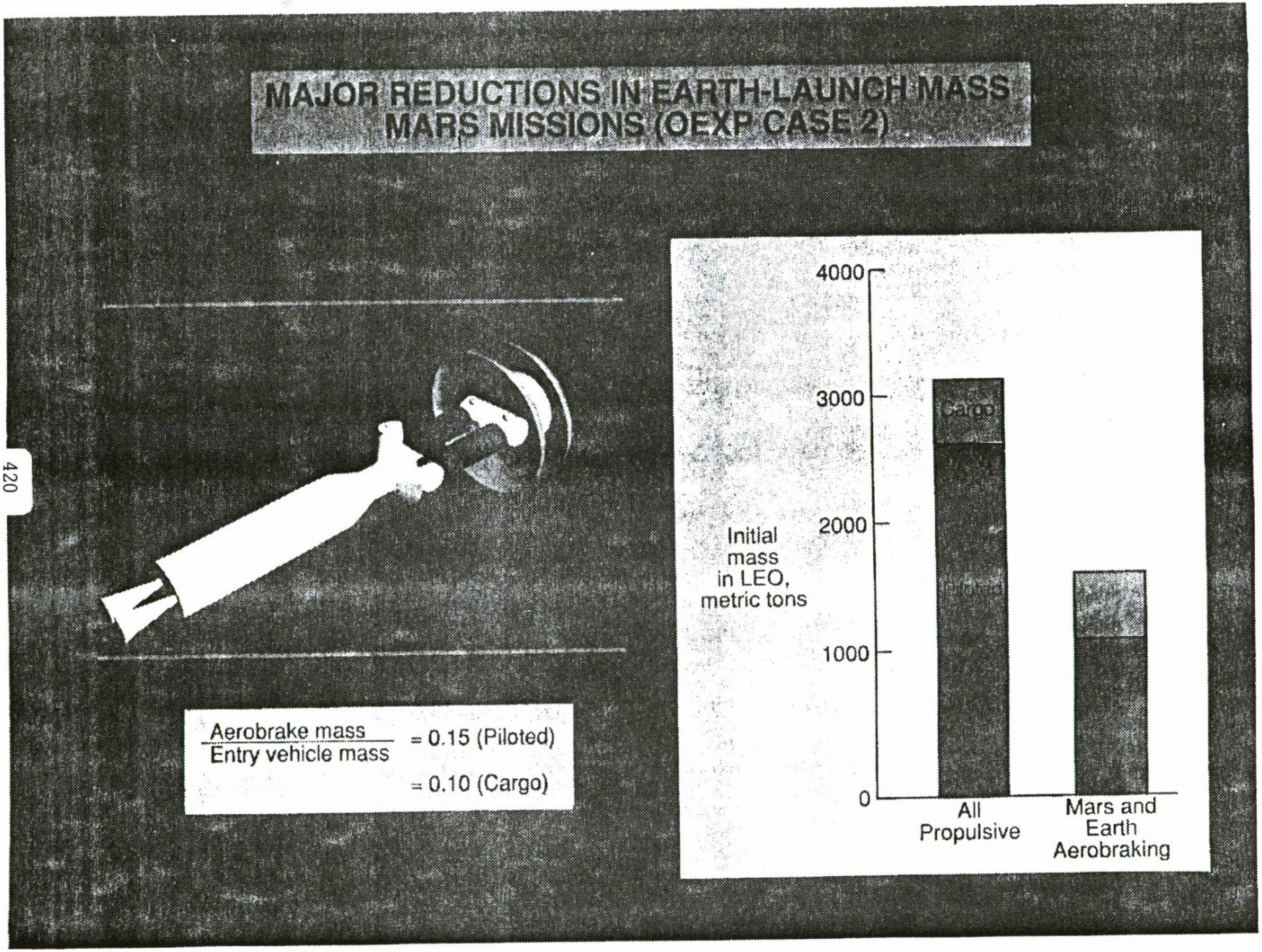
NASA
L-88-8911

MAJOR REDUCTIONS IN EARTH-LAUNCH MASS LUNAR BASE MISSION



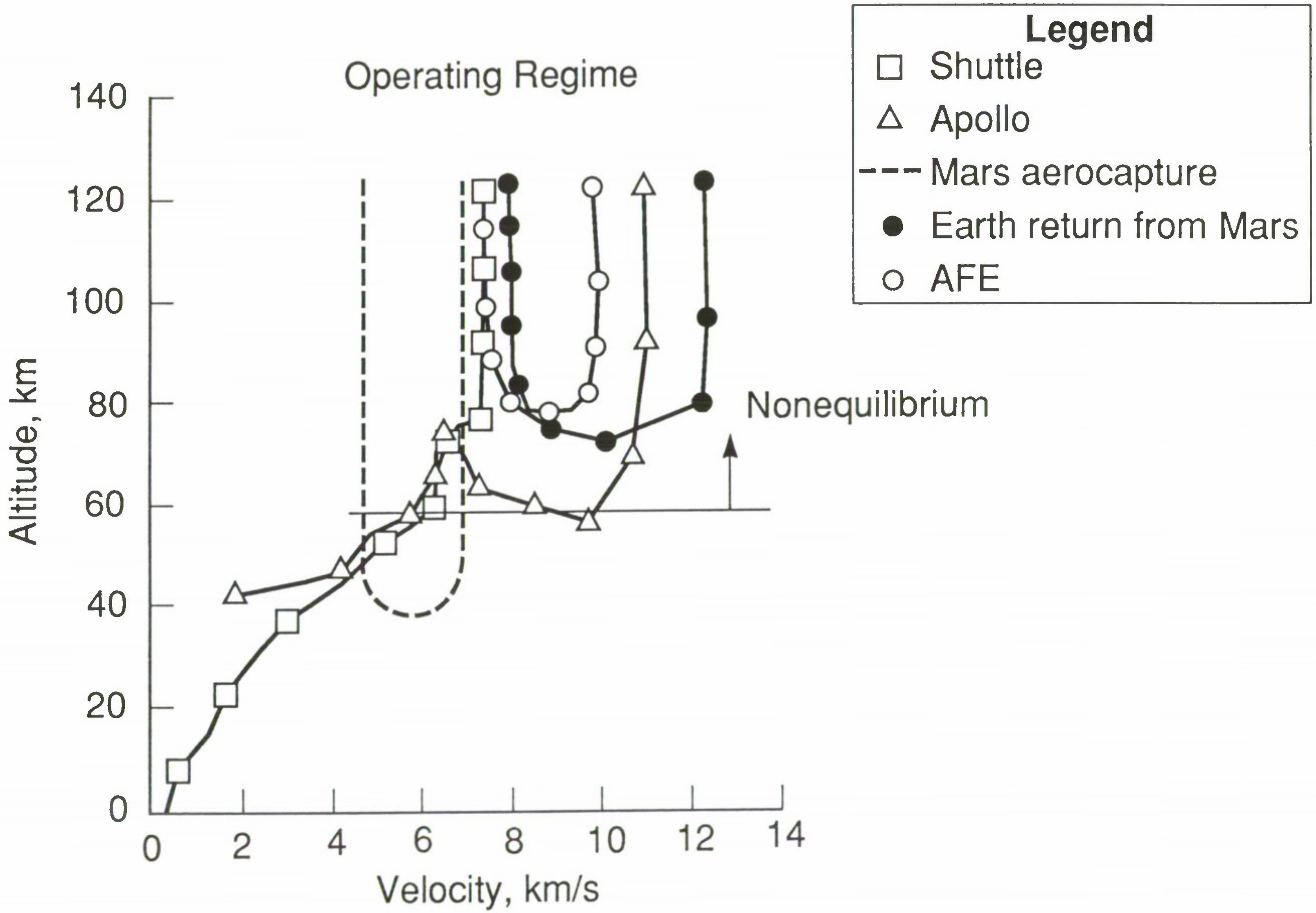


NASA
L-88-8910



EXPLORATION TECHNOLOGY REQUIREMENTS

Transportation - Aerobraking/Aerocapture



STATE OF THE ART
OVERALL

- Only partial ground-based simulation possible

- Vehicle design must be based on computational techniques

- Computational techniques now being developed
  - Lunar mission vehicle analyses nearing completion
  - Mars mission vehicle analyses require major advances

- Validation by ground and flight tests required
  - AFE provides validation for lunar vehicle analyses
  - Additional ground and flight tests required to validate Mars vehicle analyses

STATE OF THE ART
MISSION AND VEHICLE CONCEPT STUDIES

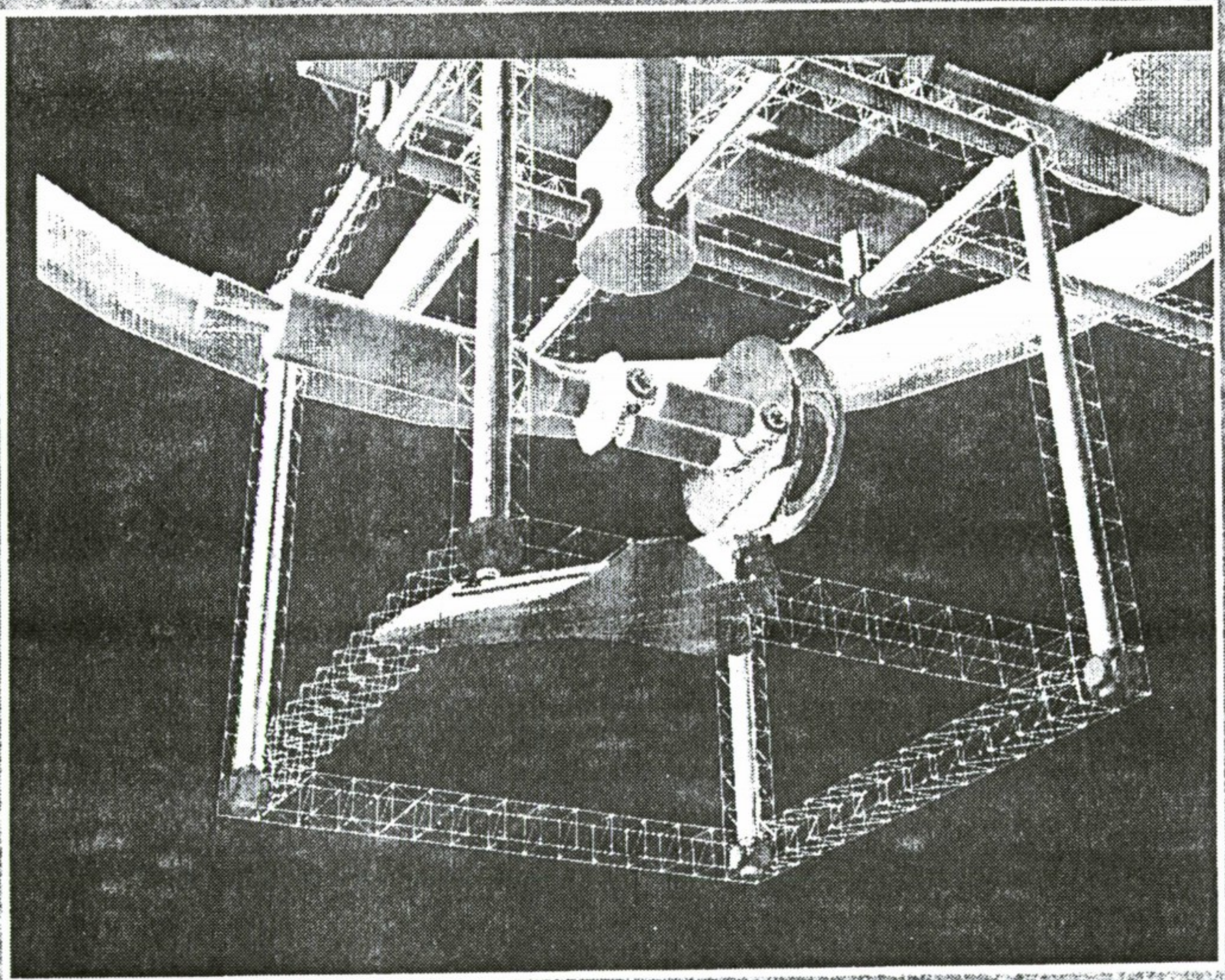
- Mission studies have scoped overall problem
  - Mars entry velocities $\approx$ 7 km/s
  - Earth entry velocities

    $\approx$ 12 km/s (MRSR)

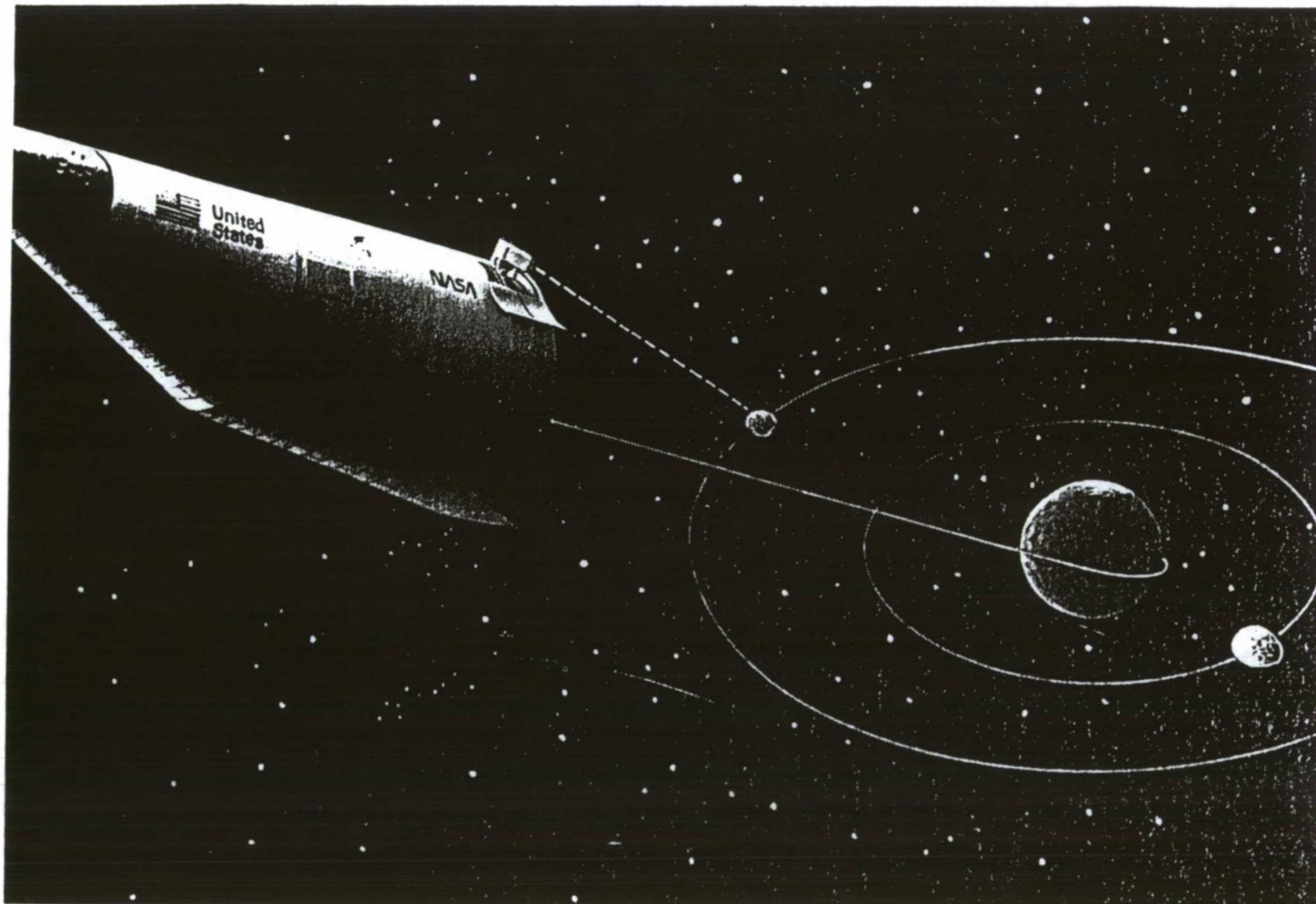
    $\approx$ 14 km/s (MMM)
  - Lightweight aerobrakes ($\approx$ 15% of vehicle mass) needed
- Detailed aerobraking-phase studies needed to complement mission studies
- Optimum vehicle geometries must be defined

NASA
L-88-891?

MANNED MARS MISSION AEROBRAKER



ON-BOARD OPTICAL NAVIGATION FOR MARS AERO CAPTURE



STATE OF THE ART AEROTHERMODYNAMICS

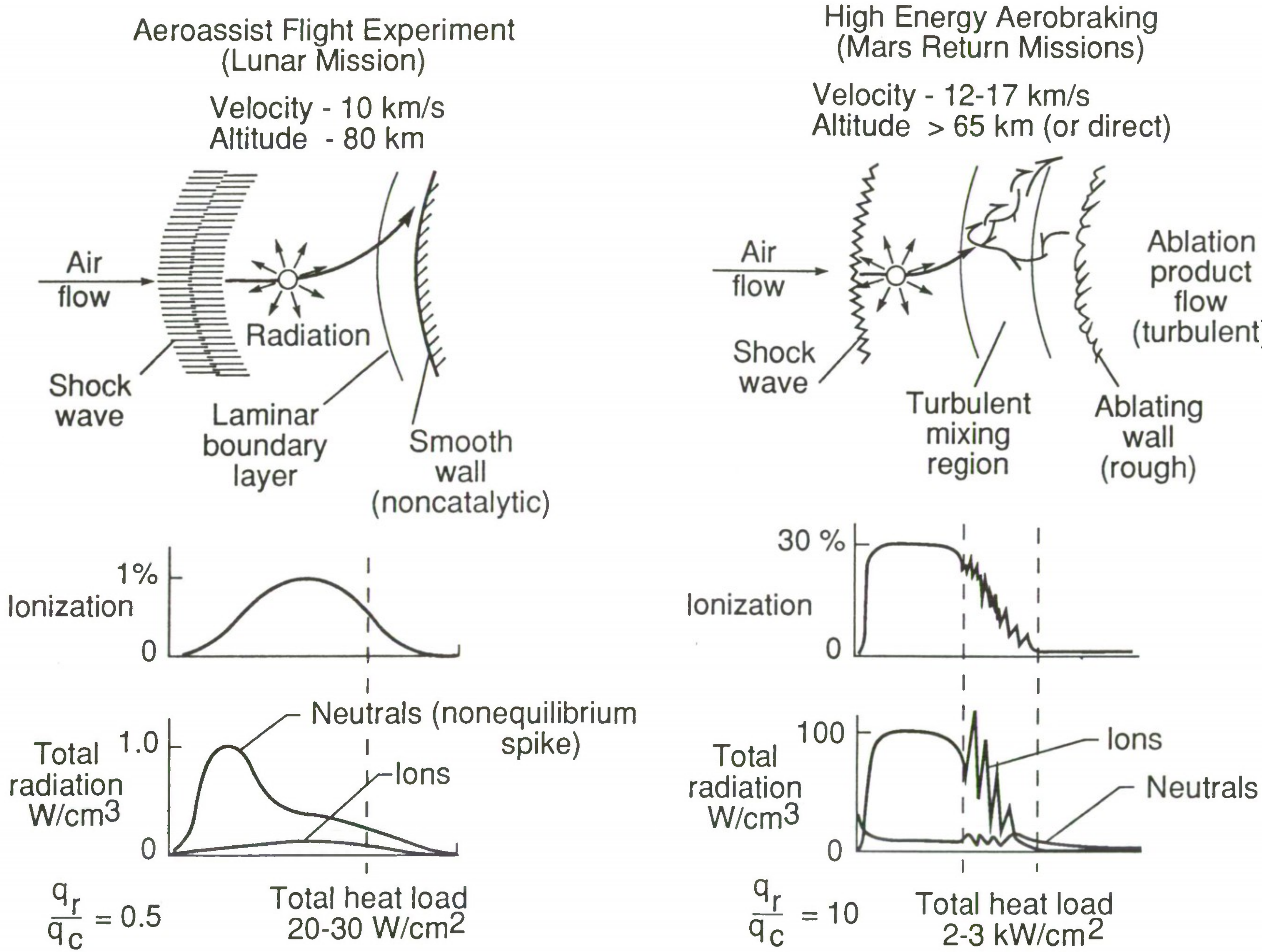
- Equilibrium forebody flow-field analyses are relatively advanced but limited to simple geometries

- Nonequilibrium forebody analyses undergoing rapid development for lunar return conditions

- Complete (forebody + afterbody) analyses in early stage of development - present emphasis on lunar and GEO return

- Analyses must be extended to include
  - Dominance by radiative processes
  - High temperature transport properties (air and planetary atmospheres)
  - Ablation product/flow-field interaction
  - Complete (forebody + afterbody) flows for arbitrary configurations
  - Turbulent and unsteady flows

SHOCK LAYER PHYSICS COMPARISON



STATE OF THE ART
GUIDANCE, NAVIGATION AND CONTROL

- An extensive literature exists for generic aerocapture missions
- Recent studies carried out for lunar return (AFE) and MRSR
- Detailed studies needed for manned Mars missions
- Key issues are
  - Advanced guidance systems
  - Approach navigation accuracy
  - Atmospheric modeling
  - Aero controls
  - In-atmosphere navigation sensors
  - Fault tolerance

STATE OF THE ART
MATERIALS AND STRUCTURES

- Sizable literature on GEO-mission vehicle design

- Detailed assessments for Mars mission vehicles needed

- Primary issues involve TPS concepts
  - Significant portions of vehicles may use new robust insulators
  - High heating regions will probably require ablators
  - Reflective concepts need to be revisited

- Additional key issues
  - Structural concepts, analyses and optimization
  - Heat shield response analysis
    - Catalytic effects
    - Ablation
    - Mars atmosphere interactions

STATE OF THE ART
FLIGHT TEST DEFINITION

- High energy aerobraking (Mars return) potentially much more challenging than lunar return

- AFE is a necessary but not a sufficient step toward validation of HEAB design techniques
  - Correct physics for Mars aerobraking but not correct chemistry
  - Focused on nonequilibrium phenomena

- For HEAB, AFE validated codes must be extended to address
  - Order-of-magnitude higher heating
  - Radiation dominated flow field
  - Ablation, turbulence
  - More stringent G,N&C requirements

- Possible approaches to HEAB flight tests
  - Dedicated research experiment
  - Synergetic MRSR certification flight
  - MMM joint technology/vehicle certification flight
  - Piggyback experiments on Phobos or other early missions

CURRENT HIGH ENERGY AEROBRAKING ACTIVITY

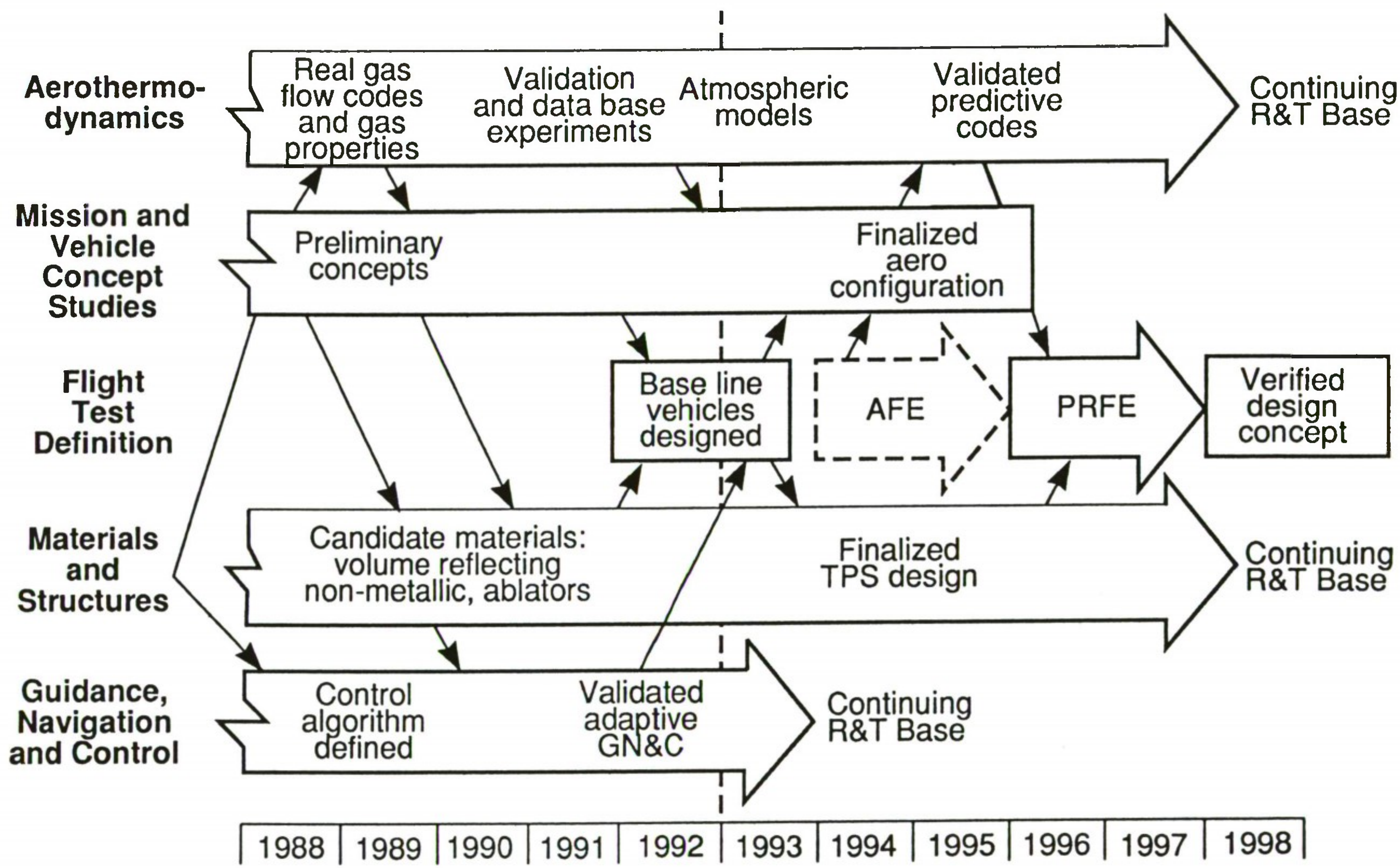
- Systems studies, analytical and experimental research under way at LaRC, ARC and JSC

- Systems studies and G,N&C research under way at JPL

- Mission studies under way at MSFC, JPL and JSC

- Numerous aeroassisted OTV studies have been carried out in industry

HIGH ENERGY AEROBRAKING MILESTONES AND DELIVERABLES



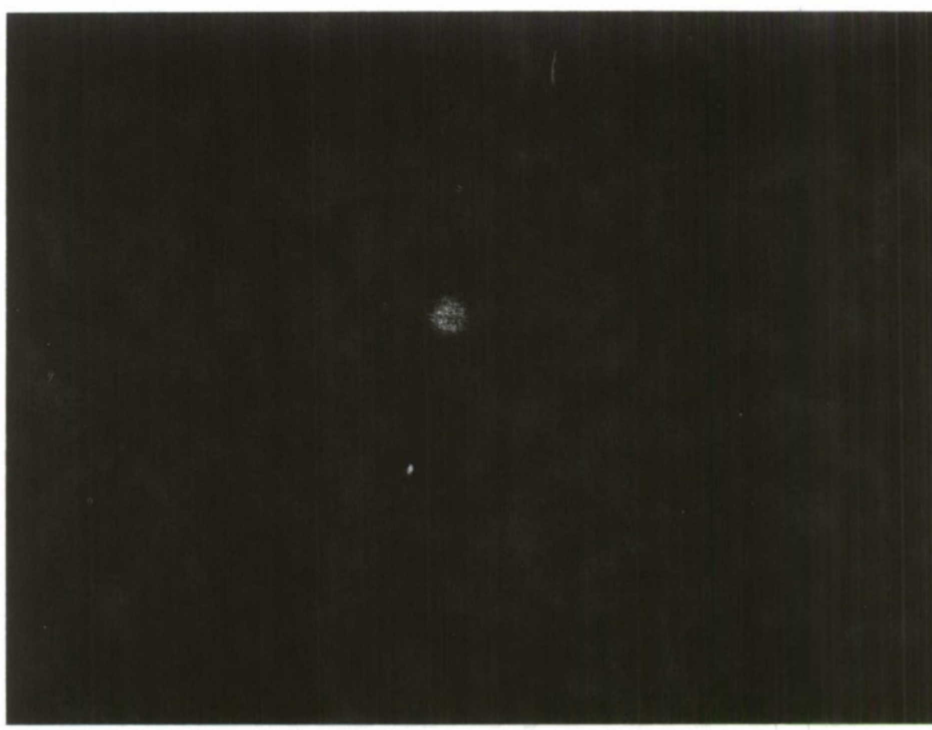
APPENDIX A

Pathfinder Preliminary Program Overview

PRELIMINARY

Pathfinder

Research and Technology To Enable Future Space Missions



Program Overview

Fall 1988

National Aeronautics and Space Adminstration

Office of Aeronautics and Space Administration
Washington, D.C. 20456

Pathfinder

For further information on the Pathfinder Program, please contact the NASA Office of Aeronautics and Space Technology, Space Directorate. (202) 453-2733

Foreword

Pathfinder is a technology initiative that will allow the National Aeronautics and Space Administration (NASA) to develop critical capabilities to enable future missions of solar system exploration. This programmatic scope includes both human exploration missions as well as robotic science missions and robotic precursors to later human expeditions.

Pathfinder is not a mission, nor is the program directed toward any specific mission concept. Through Pathfinder, the NASA Office of Aeronautics and Space Technology (OAST) will develop critical information and capabilities in the areas of surface exploration, in-space operations, humans in space technologies, and space transfer systems. Pathfinder will - as the Apollo program did during the 1960's - push American technology forward, while making future successes in space possible.

This document provides a detailed overview of Pathfinder, including its goals and objectives, technical content , and the organization and management of the Program.

Contents

Pathfinder

Chapter 1
Overview

Project Pathfinder is a new technology initiative which will allow the National Aeronautics and Space Administration (NASA) to develop critical capabilities to enable future missions of solar system Exploration. This programmatic scope includes both human exploration missions as well as robotic science missions and robotic precursors to human expeditions.

This document provides an overview of the Pathfinder program, including not only its goals and objectives, but also the technical and programmatic details of Pathfinder, and the technology thrusts and several element programs that make up Pathfinder.

Section 1.1
Background

The past 25 years of the civil space program have presented the United States with a broad ensemble of spectacularly successful planetary exploration missions. These have spanned the spectrum from the earliest automated spacecraft flybys of the Moon and Mars, through the achievement of the Apollo program's piloted missions to the Moon. Today, NASA continues that tradition of planetary exploration through missions such as Galileo to Jupiter, Magellan to Venus, and the Mars Observer. Beyond these near-term probes, the future holds still more exciting opportunities.

Since before the beginning of the U.S. civil space program, there has been considerable speculation about possible human and robotic exploration of the solar system. Over the years, those speculations have been crystallized by numerous formal studies, by NASA and others, of ambitious future missions. Recently, the National Commission on Space (NCOS) examined the prospects for future U.S. space activities and discovered an exciting vista of possibilities.

NASA is working to reexamine in detail the options and possibilities for future space

science, space operations, and the robotic and human exploration of the solar system. Studying options for future human exploration is the responsibility of the NASA Office of Exploration (OEXP). The NASA Office of Space Science and Applications

(OSSA) is responsible for robotic exploration and is conducting various missions studies, including potential precursors to human missions such as Mars rover and sample return mission concepts. To provide operational support to these missions, the NASA Offices of Space Flight (OSF) and Space Station (OSS) are studying advanced in-space operational capabilities that could be implemented in the late 1990s or the early part of the next century to support these ambitious solar system Exploration missions.[1]

The common thread that links these future possibilities is the need for substantial, across-the-board advances in space technology, coupled with the need for early information on the capabilities that technology will be able to provide. Within NASA, research and development of advanced space technology is carried out by the Office of Aeronautics and Space Technology (OAST). Through the Research and Technology (R&T) Base, OAST provides the technological foundations for the U.S. civil space program. That foundation is focused through two programs: CSTI[2] (the Civil Space Technology Initiative), and ***Pathfinder***.

Section 1.2
Goals and Objectives

There are three major goals which OAST will achieve through Pathfinder. First,

> *Pathfinder will develop critical technology opportunities for a range of future space missions - focussing on exploration of the Solar System.*

Second,

> *Pathfinder will support a National decisions regarding future missions in the early 1990s timeframe.*

And lastly,

> *Pathfinder will help to insure U.S. leadership in civil space technology development.*

To meet those goals, the Pathfinder Program must achieve the following objectives: Pathfinder must

> *Produce initial critical research results and validate key capabilities by the early 1990's (initial target: the end of 1992);*
>
> *Achieve necessary levels of readiness and transfer technologies to mission users beginning in the mid-1990's;*
>
> *Define and achieve the right balance between more basic research and focused demonstrations;*
>
> *Coordinate Pathfinder research and technology with other NASA Offices and support on-going NASA mission studies; and*
>
> *Build a lasting partnership among NASA, U.S. industry, and universities, in the implementation of Pathfinder.*

OAST has formulated the Pathfinder Program to meet these goals and objectives. The remainder of this chapter provides a description of the organization and management of Pathfinder. Details regarding the technical content of the program are provided in Chapters 2 through 5.

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1. Additional information on NASA's current efforts in Solar System Exploration mission studies is provided in Chapter 6.
2. For information on CSTI, or any other aspect of OAST's programs, please contact the OAST Space Directorate.

Section 1.3
Management & Organization

Pathfinder is a focused technology program, consisting of a suite of research and development efforts that are divided into four major program areas. These are: (1) surface exploration, (2) in-space operations, (3) humans in space, and (4) space transfer. In addition, Pathfinder supports studies of future human and robotic solar system exploration missions. Figure 1 provides the Pathfinder work breakdown structure (WBS).

Within each program area (or "thrust") are a family of closely-related element programs. (For example, the "Planetary Rover" is one of the element programs in the Surface Exploration program area). Each element program will be implemented by managers at one or more of the NASA field centers. In most cases, one of these Field Centers has been asked to serve as the "lead" for the activity. That leadership responsibility includes providing a technology project manager who will work closely with the NASA Headquarters element managers to plan a strong research and technology effort. A systematic hierarchy of plans is being set in place to integrate the Pathfinder effort, including a top-level Pathfinder Program Plan and Element program plans at NASA Headquarters, and Element Technology Project Plans at the NASA Field Centers.

In the program area and element discussions which are provided in Chapters 2 through 6, the specific NASA Headquarters and Field Center management assignments for the various elements are provided.

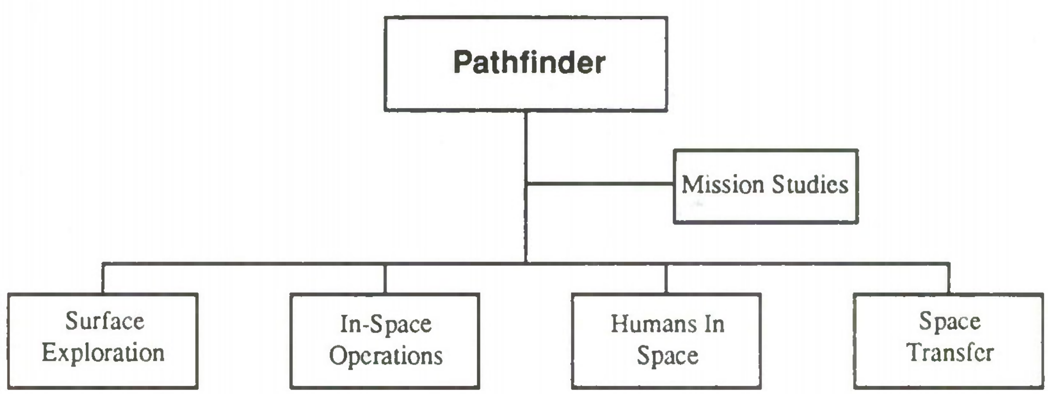
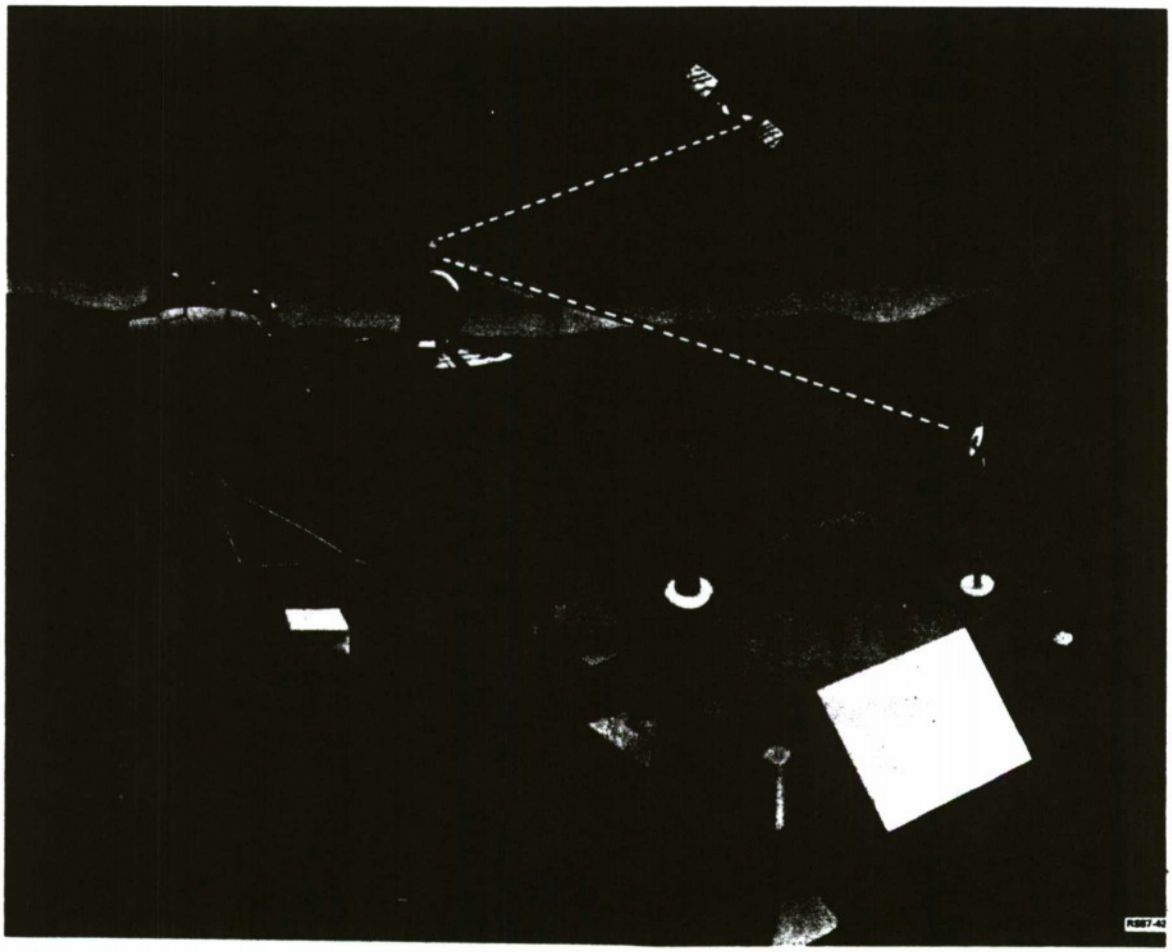


Figure 1
Top-Level Pathfinder Work Breakdown Structure



Chapter 2

Surface Exploration

The objective of the Surface Exploration program area is to develop critical technologies to enable or enhance significantly future piloted and robotic exploration of planetary surfaces. The principal focus is on two mission goals: the exploration of Mars, and the beginning of extended human operations on the Moon.

The exploration of planetary surfaces has been an important aspect of Solar System exploration since the 1960s. Robotic precursor spacecraft and piloted Apollo lunar excursion modules (LEMs) visited the surface of the Moon during the first decade of the U.S. civil space program. During the expeditions, a combination of stationary robots and astronauts using "rovers" provided an exciting glimpse of what "surface exploration" might entail.

During the 1970s, the Viking robotic spacecraft landed safely on the surface of Mars and conducted numerous experiments while orbiting spacecraft provided long-term global images of the planet's surface. However, the Viking spacecraft could not move from their landing sites - and the horizon always sat, beckoning, just beyond the reach of the landers' television cameras and scientific instruments.

The Pathfinder Surface Exploration program area will create the capabilities needed to permit a new era of piloted and robotic planetary surface exploration expeditions. The activity consists of five element technology programs: (1) Planetary Rover, (2) Sample Acquisition, Analysis, and Preservation, (3) Autonomous Lander, (4) Surface Power, and (5) Photonics.

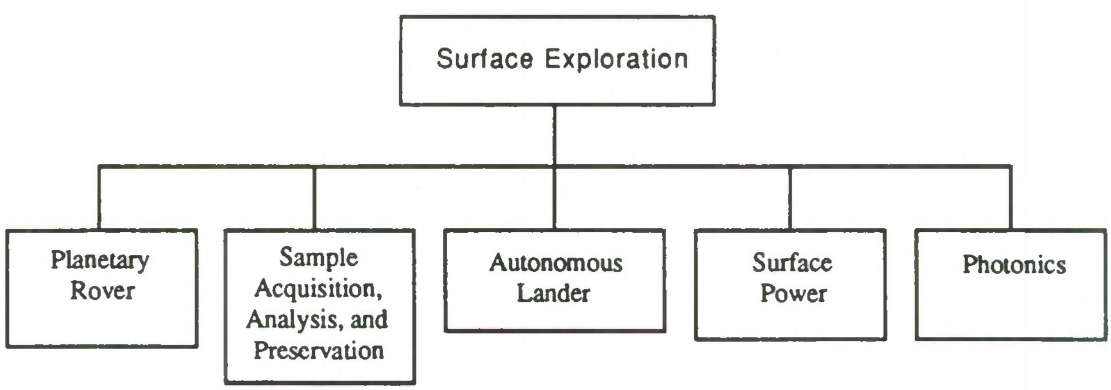


Figure 2
Work breakdown structure for the Pathfinder Surface Exploration Program Area

Each of these element programs is described in the subsections which follow.

Section 2.1
Planetary Rover

2.1.1 Technology Requirements

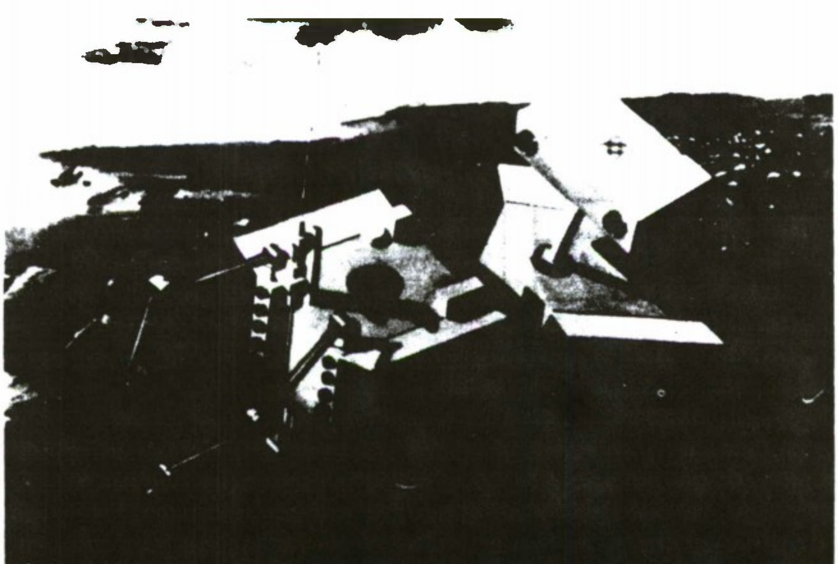
NASA's planning for the future exploration of the Solar System includes both piloted and robotic missions to the Moon and Mars. Most - if not quite all - of the mission scenarios under consideration include the use of mobile surface vehicles to conduct exploration, gather samples, and deploy scientific payloads. Mars rover and sample return mission concepts that are currently under study are one such potential application of "Planetary Rover" technologies. Scenarios involving the creation of human installations require "rovers" to support both construction and surface mining operations; these systems may be autonomous, teleoperated, piloted, or a variable combination of the three.

Early applications of planetary rovers will be robotic systems with varying requirements for levels of on-board autonomy. Key technologies needed for robotic planetary rovers include: surface mobility, local guidance and hazard avoidance, compact and rugged power systems, and a degree of on-board autonomy. The capability to acquire and analyze surface and subsurface samples, to store those samples, and to preserve them for later study and possible return to Earth is key to the success of many planetary rover mission applications. (Those technologies are addressed under the Pathfinder Sample Acquisition, Analysis, and Preservation Program.)

2.1.2 Technology Assessment

There is currently no established program to develop and demonstrate in a systematic fashion the suite of technologies that will be required to make possible robotic planetary rovers. Key technologies that must be considered include: (1) mobility, (2) local guidance and navigation, (3) on-board autonomous or semi-autonomous operations (including required computational capabilities), and (4) power systems.

No flight-qualified computer technology now exists that will permit a reasonable level of autonomy on a semi-autonomous rover. Means of mobility, local guidance and navigation - autonomous



Conceptual illustration of a planetary rover exploring the surface of Mars

and semi-autonomous - across unmarked and difficult terrain are at an early stage of development. Some semi-autonomous navigation systems have been demonstrated in very controlled environments, but they are not yet suitable for a rover operating in a primarily unstructured and/or unknown environment.

The state-of-the-art in mobile systems is represented by high-speed, all terrain, vehicles designed for battlefield applications and by experimental vehicles. None of these is designed for long-term, low-speed, autonomous operations in very rugged terrain. None have the capability to sense terrain problems (for example, cliffs) and avoid them. Similarly, no automated vehicles exist that are capable of failure recovery operations such as self-righting.

In addition, planetary rover systems must also meet constraints regarding packaging for flight (for example, within the constraints of a planetary aerobraking aeroshell), mass constraints for structures and mechanisms, and deployment from a surface lander.

Low-mass, compact power systems capable of driving a mechanically and electronically complex vehicle over rugged terrain do not exist. Modular radioisotope thermoelectric generators (RTGs) which are projected to be the most probable power source for robotic rover applications are being developed under an existing Department of Energy (DoE) program, but the efficiency of planned solid state conversion materials is low.

The technology for semi-autonomously identifying, selecting, acquiring, and preparing samples for analysis is at a conceptual stage - no programs currently exist. The state of the art in telerobotic manipulation systems for space applications is represented by the ongoing NASA telerobotics demonstration program, which is a part of the Civil Space Technology Initiative (CSTI).

2.1.3 Program Description

The long-term goal of the Planetary Rover Program is to develop and validate the technologies needed to enable both robotic and piloted exploration of various planetary surfaces. The Planetary Rover Technology Project will establish technology options for a wide assortment of potential future NASA Solar System exploration missions, and demonstrate technology readiness for selected applications. Planetary Rover efforts will encompass piloted, teleoperated, telerobotic, and robotic exploration systems capable of mobility and operations on planetary surfaces.

The near-term objectives of the technology project are: (1) development of a solid foundation of systems analyses, technology requirements and planning, and technology validation requirements and plans for the project; (2) establishment of an early National foundation in advanced rover technology concepts (including autonomy, mobility, and guidance), and (3) providing for demonstrated technology readiness for both an early, and evolutionary rover for project robotic Mars rover and sample return mission concepts.

The near-term program will also focus on developing selected key technologies for robotic rovers, demonstrating those technologies - as appropriate - in an integrated testbed, and conducting studies of advanced, high- leverage rover architectures as well as programmatic and technical options for the later development of piloted rover technologies and systems.

The Planetary Rover Program will integrate and extend the "Autonomous Planetary Rover" work which is being conducted in fiscal years 1988, '89, and '90 at the

Carnegie Mellon University (CMU) Robotics Institute under a NASA OAST grant. The program will also build upon terrestrial programs of the DoD, including DARPA's strategic computing program and autonomous land vehicle program, the VHSIC advanced computing program, and on DoE's modular RTG program.

The program will balance research into new, high-leverage technologies - such as advanced thermoelectric conversion materials and on-board software for systems autonomy - with focused demonstrations of those technologies and others developed by other NASA and non-NASA programs.

Deliverables

PHASE I. By the early 1990's various concepts for semi-autonomous rovers will be proven in order to provide a basis for further technology and mission planning. The current Mars rover and sample return mission study will provide considerable source material for the formulation of realistic technology performance objectives for the program. Moreover, if an agency decision is made to move forward with a 1998-launched robotic Mars exploration mission program, the Planetary Rover Program may be re-scoped.

PHASE II. By the late 1990's, it is projected that the program will consist of two major segments: (1) incorporation of advanced navigation and computation into robotic rovers for increased autonomy, and (2) development of basic technologies and a testbed for piloted rovers.

2.1.4 Organization and Management

Work Breakdown Structure (WBS). The Planetary Rover work breakdown structure

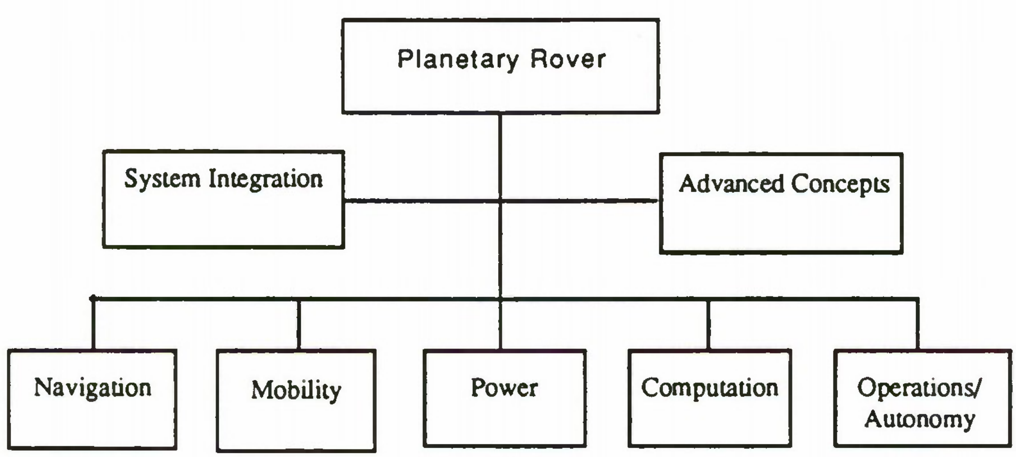


Figure 2-1
Work breakdown structure for the Pathfinder Planetary Rover Technology Project

(WBS) is directed along technology discipline lines, as well as providing for effective management of rover technology demonstration activities. Figure 2-1 provides the WBS for the program.

Management Structure. The overall program will be managed by a Program Manager in the OAST Information Sciences and Human Factors Division (RC). An Assistant Program Manager for Rover Power Systems will be appointed from the OAST Energy, Power and Propulsion Division (RP).

The lead center for the Planetary Rover technology project is JPL. This center will have responsibility for the development of a project plan and for administration of the plan throughout the program. A Technology Project Manager will be assigned at JPL for that purpose. Participating Centers include: JPL, ARC, JSC, LaRC, and LeRC.

Program Coordination. Planetary Rover efforts will be closely coordinated with the Office of Space Science and Applications (OSSA) and the Office of Exploration (OEXP). Within OAST, coordination will be maintained with the on-going CSTI programs in the areas of automation and robotics and with the RM Program Manager for the Pathfinder Sample Acquisition, Analysis, and Preservation Program. A lesser degree of coordination will be maintained with the Pathfinder Photonics Program. General coordination will also be maintained with the DARPA Strategic Computing Initiative, the SDIO advanced computing and Very High Speed Integrated Circuits (VHSIC) programs, and the DoE RTG and Dynamic Isotope Power System (DIPS) programs.

Resources. In order to accomplish the goals and objectives of the Planetary Rover Technology Project as currently envisioned, resource requirements for fiscal years 1989 to 1993 are projected to be approximately \$105 million. The funding allocation for FY 1989, the first year of the effort, will be approximately \$5 million.

Section 2.2
Sample Acquisition, Analysis, & Preservation

2.2.1 Technology Requirements

Sample Acquisition, Analysis and Preservation (SAAP) is a technology program in support of a wide range of future unmanned and manned missions in which extraterrestrial planetary material is to be acquired, analyzed and preserved. The initial focus will be unmanned missions with particular emphasis on supporting the technology needs of a Mars rover mission with sample return to Earth. Although the technologies discussed here are most frequently associated with a rover, they can also be used on landers, ascent vehicles or other surface traversing systems.

Proposed Mars rover and sample return mission concepts will be taken as representative of an SAAP-oriented mission and will be used to develop a technical focus and general structure for the first five years of the SAAP program. In particular, a Mars rover and sample return mission would use a sophisticated rover to explore an area of Mars and return samples to an ascent vehicle for return to Earth. During traverses, samples in the form of rocks, soil and corings will be collected. A basic requirement is to obtain fresh, unweathered rock. Environmental control including temperature, vibration, radiation, etc. will be required for many samples, especially cores. Once collected, the samples may

also require on-board preparation such as crushing, sawing, polishing etc., before analysis or storage. Since the mass that can be returned to Earth is relatively small (approximately 5 kg), careful screening and on-board analysis is required to provide the widest range of information about the composition and structure of the planet.

The SAAP subsystem, working in concert with a rover, should have the ability to identify promising sites and locate scientifically interesting surface samples. This will require imaging and ranging instrumentation to provide multi-spectral data for precise sample location. The SAAP subsystem should have the ability to acquire the desired samples using autonomous systems to generate, pick up and/or drill Martian materials. Once acquired, on-board equipment would process the samples for presentation to instruments or for storage. Instruments will determine the sample's elemental, chemical and physical properties for transmission to Earth and in order to make decisions on which samples to keep. The selected samples then must be preserved in a pristine condition for delivery to the ascent vehicle. On the ascent vehicle, samples could be analyzed in greater detail and/or stored in a controlled environment for return to Earth.

2.4.2. Technology Assessment

Our knowledge of the Martian surface has not increased significantly since the Mars Viking missions. The Viking Landers provided very good characterization of general terrain features and rock size distributions (within centimeter accuracy), but only within camera view around the landing sites. In addition, detailed surface maps were developed by the Mars Viking Orbiters, but the best resolution obtained from orbit was ten meters. Thus, detailed features of most of the Martian surface are basically unknown.

Likewise, the state of the art technology for space-qualified, planetary sample acquisition, sample analysis, and sample preservation has also not substantially advanced since the Viking missions. The instrumentation included on the Viking landers were an x-ray fluorescence spectrometer to analyze inorganic matter, and a gas chromatograph mass spectrometer to analyze organic material in the soil. There was no capability to conduct direct mineralogical analysis. Other major limitations included: no ability to crack rocks or to take a sample more than a few inches below the surface, and the x-ray fluorescence spectrometer could only detect elements with atomic numbers greater than 11--thus excluding significant elements such as hydrogen, oxygen, nitrogen, and carbon.

At the present time, there are some new analytical instruments being developed as part of a proposed comet rendezvous mission, the Comet Rendezvous/Asteroid Flyby (CRAF) mission. These include a lightweight spectrometer (about 18 kilograms), which is sensitive to wavelengths between 0.3 and 5.0 microns; a scanning electron microscope/particle analyzer (about 11 kilograms); and a differential scanning calorimeter, which can be used for mineralogical analysis. All three instruments may be adaptable for use on an MRSR mission, but each has its limitations. For example, the spectrometer, although lighter than the VIking instrument, still has the disadvantage of being only sensitive to elements of atomic number greater than 11. Also, the calorimeter is designed for the ballistic penetration of a comet and would have to be redesigned for planetary surface use.

Currently, there is an existing team of specialists actively working to define an MRSR mission more concretely. They are addressing such areas as acquisition

methodology, instrumentation for analysis, mechanical tools for acquisition, and containment and preservation of samples. However, there is no integrated technology program in place to develop the required capabilities.

2.4.3 Program Description

The Sample Acquisition, Analysis and Preservation element of Pathfinder will develop the technologies required to return to Earth scientifically valuable specimens from a planet's surface and near-subsurface. The SAAP element will concentrate on enabling technologies in the following areas: site and sample recognition and selection, sample acquisition, preparation and processing, sample analysis, and storage and preservation.

To allow the widest range of mission options, the program will produce a technology base that can be applied to a variety of mission scenarios. This will lead to the development of hardware systems that are adaptive, compact and rugged, and software systems that are intelligent and robust.

Initially, the technology developed in this element will be coordinated with the needs of the Mars Sample Return Mission. The technology needs will be prioritized and only those technology areas which are considered to be enabling will be addressed. The long range objectives will be to address Project Pathfinder's goals of developing the technology which will enable the broadest range of unmanned and manned missions.

An overall SAAP system concept design will also be developed. This activity will be performed in close cooperation with the Planetary Rover element of Pathfinder. SAAP and Planetary Rover technologies may ultimately be integrated to demonstrate a fully operational technology base.

The following technical approach is being followed for SAAP: (1) determine the technology to be developed in each area, (2) evaluate the technology readiness and criticality, (3) select critical technology areas, (4) determine concepts for developing technology, (5) develop and test concepts analytically and experimentally, and (6) integrate technology disciplines into a SAAP testbed.

The program emphasis for the first 5 years is delineated in the following groupings by priority. It is anticipated that all the primary and secondary elements will be brought together for an overall technology demonstration/validation in the FY '92- 94 timeframe. Primary emphasis will be placed on: (1) SAAP system design, (2) site and sample recognition/selection, (3) sample preparation and analysis methods, (4) rock core drilling, (5) sample acquisition tools, and (6) containment concepts. Secondary emphasis will be placed on: (1) long-term environmental control, (2) soil coring and (3) integrated testbed development. These areas will emphasized more heavily during the second phase of the program. In particular, the testbed will be developed from a laboratory system into an integrated transportable system and used for "field" experiments in an appropriate earth-based environment.

Deliverables

Under this program, sample acquisition, analysis, and preservation technologies will be developed in two phases.

PHASE I. By the early 1990's, key enabling technology concepts will be developed to support late-1990 sample return missions, and to aid in the development of a long-range NASA technology program. An overall SAAP system conceptual design will be developed which will lead to an integrated testbed.

This will include identifying all key functional elements of a SAAP system, how these elements work together and the mechanical and operational concepts. In addition, a comprehensive evaluation of the state of the art of each technology discipline will be initiated and new technology will be developed to fill in the gaps. An evaluation of physical, elemental, and chemical analysis methods will be conducted, a concept for a complete sample analysis system will be defined, and concepts to overcome key technology barriers will be developed. Concepts will also be developed for the selection, identification and the acquisition of samples as well as for containing and preserving the planetary samples so that they may be returned to Earth in a pristine condition. In addition, concepts for specialized tools will be developed for surface and subsurface sample collection such as drilling and coring. Laboratory hardware will be developed for validation in an laboratory testbed environment.

PHASE II. By the late 1990's, concepts and hardware will be developed to the point that work could be initiated on a flight system. Key issues involving space durability (especially in a Martian environment) will be identified and satisfied. A laboratory testbed with realistic operational capability will be developed and tested in an "open" earth-based environment to validate systems-level capability of the overall SAAP concept.

Artist's conception of a core sample being analyzed after being obtained from below a planetary surface

2.4.4 Organization and Management

Work Breakdown Structure. The SAAP work breakdown structure (WBS) is outlined in figure 2-2. The WBS for the program will consist of five tasks: (1) site and sample selection, (2) sample acquisition, (3) sample analysis, (4) sample containment and preservation, and (5) system design. Site and Sample Selection will focus on developing methods to survey a possible site remotely and identify potential samples for analysis. Sample Analysis will develop technology to enable physical and chemical instrumentation to be developed for a rugged compact SAAP system and associated methods for assuring efficient use of on-board instrumentation and on-board interpretation of analytical data. Sample Containment and Preservation will develop materials and concepts to assure Earth return of samples in pristine condition. System Design will develop concepts for an integrated SAAP system and will design and build a SAAP testbed representative of such a system.

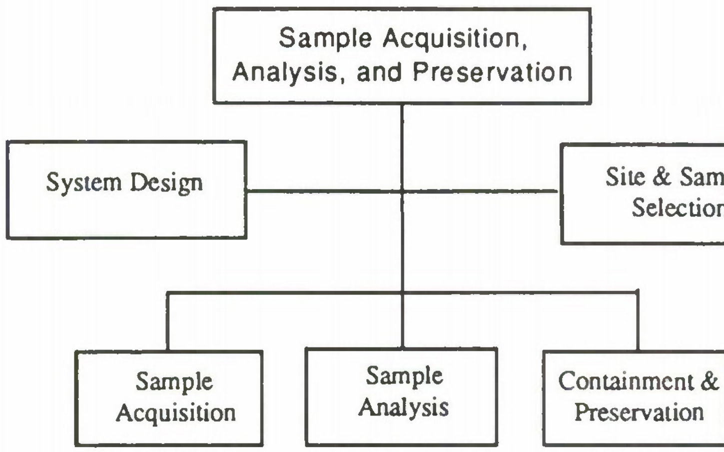


Figure 2-2
Work breakdown structure for the Pathfinder Sample Acquisition, Analysis, & Preservation Technology Project

Management Structure. The overall program will be monitored by a Program Manager in the OAST Materials and Structures Division (RM). A technical advisory committee will be established to review the course of planning and progress and to advise the RM program manager. The advisory committee will include members from several OAST Divisions, including RS and RC, and from OSSA and OEXP.

The Jet Propulsion Laboratory (JPL) has been identified as the lead center for the program. JPL will appoint an SAAP Technology Project Manager. The Technology Project Manager will have responsibility for technology integration of all activities, planning, and reporting. Other participating centers will include the Johnson Space Center (JSC) and the Ames Research Center (ARC).

An SAAP Technology Working Group will be created. It will be chaired by the JPL SAAP Technology Project Manager and will contain members from each participating program center, and from the Pathfinder Planetary Rover Program. The group will be the primary mechanism for coordinating planning for the program, for ensuring that the various elements are technically integrated (especially the Mars rover and sample return mission study and the Pathfinder Planetary Rover Program), and/or providing technical peer review.

Program Coordination. The program will be coordinated with the on-going OAST Research and Technology Base program, with the other elements of Pathfinder (in particular, with the Planetary Rover Program) with a Mars rover and sample return mission concept, with the Office of Exploration (OEXP), and with the Office of Space Science and Applications (OSSA).

Resources. To accomplish the goals and objectives discussed above, the resource requirements of the Sample Acquisition, Analysis, and Preservation Technology Project have been projected to be approximately $24 million for fiscal years 1989 through 1993. The funding allocation for FY 1989 will be at the $1 million level.

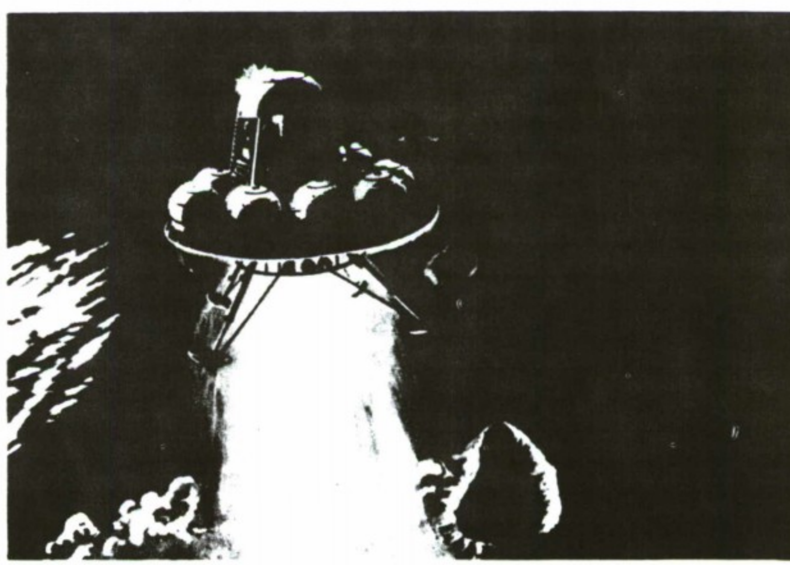
Section 2.3
Autonomous Lander

2.3.1 Technology Requirements

NASA's planning for the future exploration of the Solar System includes both piloted and robotic missions to the Moon and Mars. In particular, a robotic Mars rover sample return mission, a piloted expedition to Mars, and the installation of a human outpost on the Moon are all being studied. The success of each of these projects will require the capability to land a planetary exploration spacecraft safely in the face of surface hazards such as rocks and slopes, and accurately, close enough to scientifically-interesting targets to meet mission requirements.

Generic Solar System exploration mission requirements associated with surface landings include: (1) acceptable levels of risk during landing, (2) non-excessive structural mass needed to survive touchdown in the vicinity of large rocks and steep slopes, and (3) acceptable limits on the operational resources required to survey a target area until an acceptably "safe" landing site is located. In addition, round-trip-light-time (RTLT) communications delays will preclude the use of ground-based control of surface landing operations. In the case of a robotic mission to Mars, RTLT delays can be on the order of twenty minutes; therefore, the landing on Mars must be made without real-time human control. In the case of piloted Mars expeditions (RTLT delay approximately 20 minutes) or a Lunar outpost (RTLT delay approximately 2 1/2 seconds), landings will be made using only local - not Earth-based - human control.

Therefore, approaches considered for lander technologies must be consistent with the rigorous constraints associated with deep space spacecraft; these include constraints on power, mass, volume, and on-board computing capacity. (Within a program, any approach is also constrained by projected schedules for the implementation of these missions.) For example, assuming a Titan IV/Centaur launch vehicle and the



The capability to land precisely and to avoid surface hazards will greatly improve the reliability and returns from future surface exploration missions

use of aerocapture for Mars orbit insertion, a landed mass on the order of one thousand kilograms (1000 kg) could be achieved for a Mars rover and sample return mission mission. Clearly, one critical mission requirement will be for the Mars Lander's landing hazard avoidance system to consume only a small portion of that available mass (perhaps approximately 100 kg).

In the areas of guidance, navigation, and control (GN&C) mission requirements will necessitate the capability for a precision landing, for example within a one kilometer (1 km) error ellipse around the landing target. Also, local hazard detection and avoidance will be required during the terminal phase of a landing; for example, the final six kilometers of altitude and ninety seconds of time during which the lander will utilize a parachute followed by a terminal descent engine to achieve a soft landing.

2.3.2 Technology Assessment

Two robotic Viking spacecraft landed safely on Mars in 1976 without the capability to detect and avoid surface hazards. However, a post mission analysis indicates that there was a non-negligible probability (>10%) of landing failure due to surface hazards. In the Apollo program, the crew provided on-board, real-time control in case the need arose to avoid a Lunar surface hazard during the final moments of landing.

The Space Shuttle has an "autoland" system; however, it depends on the existence of surface navigation aids. Therefore, although in general NASA has demonstrated a landing capability, it has not demonstrated the technology required for autonomous landers. The technical challenge for Solar System exploration systems lies in detecting an acceptable landing point close to a preselected target site, based on limited information, and landing safely there.

In the image analysis technology community, many techniques have been developed for detecting objects in images and performing specific processes (such as labeling) on those objects. However, there has been no focus on detecting hazards in real-time and avoiding them via an integrated GN&C system for the purpose of a safe, high-speed landing on a planetary surface.

2.3.3 Program Description

The goal of the Pathfinder Autonomous Lander Program is to develop and demonstrate the technology required to land a planetary exploration spacecraft safely in the face of surface hazards provided by rough terrain, while still landing close enough to the intended target site to meet mission requirements. In order to achieve this goal, the program will be designed to achieve the following objectives:

(1) Establish mission constraints and requirements,

(2) Develop and demonstrate the technology required to enable precision landing at a preplanned site, and

(3) Develop and demonstrate the technology required to enable real-time hazard-avoidance during final landing stages. This will require specific advances in the areas of sensors for hazard detection, algorithms for image matching, scene understanding and guidance, and real-time image processing.

The Autonomous Lander Program will follow a general strategy of systems analysis and evaluation using simulation, followed by instrument and algorithm

development, followed by demonstrations. The demonstrations will be performed first using a ground testbed and then via simple 1-gravity atmospheric flight tests.

Some initial systems analysis work conducted by a Mars rover and sample return mission study during its current pre-Phase A activities suggests that candidate technical approaches to the safe landing problem may be divided into two classes: first, the "precision landing class", and second, the "hazard detection and avoidance class". The early efforts of the Autonomous Lander Program will be organized on that basis.

The program will begin with the definition of mission requirements and constraints. This activity will cover the full range of missions that will require autonomous landing capabilities, including both Lunar and Mars missions. Initial efforts will focus on the approaches required for the project robotic Mars Rover/Sample Return mission. Mission requirements and constraints will be identified by the end of the first year of the program.

Deliverables

At the end of the first year, work will begin on a relatively simple prototype system that will demonstrate the current state-of-the-art in several critical technologies. This prototype system will be used to better identify the technology areas that need further advancement. Although this approach will provide a focus for early technology efforts, it will not exclude research and development of more advanced techniques that are not yet ready for demonstration.

Development needed to address the two major issues in autonomous landing will also begin in the first year of the technology base. These two areas are (1) precision landing at a pre-identified location, and (2) hazard avoidance during the final stages of landing (which can include real-time site selection during the landing process).

Technologies for precision landing at a pre-identified location are closer to being state of the art today and will be the first technical area to reach readiness under this program. By the end of the second year, the technology in this area will be demonstrated by simulation. By the third year, technology in this area will be ready for insertion into a testbed for high-fidelity demonstration.

The more challenging and more desirable technology area is the development of the capability to choose the final landing site in real-time. The objectives during this phase of the landing will be to avoid any specific hazards that were not identified prior to site selection, or to maximize the probability of good scientific value for the mission. Technological development to address this issue will require significant advancements in a number of related areas; these include real-time image processing, on-board computing, and sensors for hazard detection. These technologies will be demonstrated in simulators by the end of the sixth year of the program and will be ready for testbeds in the following year.

Flight tests of the techniques that have been demonstrated in ground testbeds will occur in the fifth and eighth years of the program. These flight tests are envisioned as 1-g tests that will demonstrate the techniques, but will require compensation for the Earth gravity. The system that will actually be flown on planetary missions will probably be a combination of both the precision landing capability and the hazard avoidance technologies that will be developed in this program. Clearly, the mission application system will be optimized to make the best use of on-board computing power and pre-landing available site information.

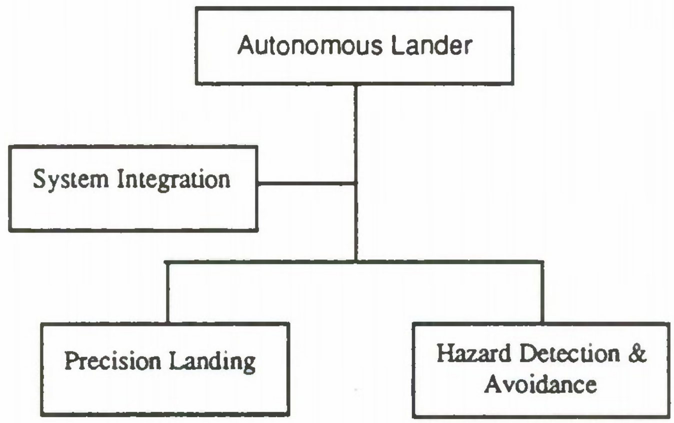


Figure 2-3
Work breakdown structure for the Autonomous Lander Technology Project

2.3.4 Organization and Management

Work Breakdown Structure. The work breakdown structure (WBS) is divided into systems engineering activities and into several classes of issues and approaches to the autonomous landing problem as described in the Technical Approach above; these are Precision Landing and Hazard Detection and Avoidance. The preliminary work breakdown structure (WBS) thus consists of three elements. Figure 2-3 provides the preliminary WBS for the program. This WBS will be revised and refined during the course of the next several months of detailed program planning.

Management Structure. The Autonomous Lander Program will be managed by a Program Manager in the Information Sciences and Human Factors Division of OAST (RC). Program advice and coordination will be provided by the "Autonomous Lander Working Group", which is made up of representatives from the NASA Centers having those NASA Offices that would be potential users of this technology.

The lead center for the Autonomous Lander Technology Project will be JSC. Planning, integration and reporting will be performed by the NASA Center coordinator. Quarterly technology project reports will be submitted to OAST which track progress against Level 1 schedules and identify any problems, issues, or significant accomplishments. Additional NASA centers will be designated as needed to implement specific tasks within the technology project.

Program Coordination. This program will require coordination with the following NASA offices and programs: (1) the piloted exploration mission definition studies of the Office of Exploration (OEXP), (2)

development programs for high-capacity, flight-qualified computers being conducted by OAST, (3) the Mars Observer Flight Project being conducted by the Office of Space Science and Applications (OSSA), and (4) the Mars Rover/Sample Return mission study being conducted by OSSA. Coordination with the two OSSA programs is important because of the lack of detailed information about the surface of Mars in the one meter object size range, which makes it difficult to assess the degree of hazard at potential landing sites. Coordination with space computing technology developments is also critical because some of the candidate approaches require a real-time, on-board image processing capability.

Resources. Resource requirements for the Autonomous Lander Technology Project for the fiscal years 1989 through 1993 are approximately $32 million. The funding allocation for FY 1989 will be at $1 million.

Section 2.4 *Surface Power*

2.4.1 Technology Requirements

NASA's planning for the future exploration of the Solar System includes both piloted and robotic missions to the Moon and Mars. A substantial technology challenge for current and projected space power systems capabilities is the support for human expeditions to the Moon, Mars and its moons, and human operations on the Moon and later Mars. Although the high levels of power associated with an operational outpost - somewhere in the 1000 kilowatt range - will require space nuclear power systems, during the installation of those permanent systems, power systems based on solar energy show the greatest promise. Such relatively small, solar energy-based power systems will also be required as emergency and/or back-up power sources.

Low system mass for a given power level is a critical requirement in order to reduce transportation costs. Another requirement is for appreciable system lifetimes - including dormancy and storage - in order to ensure highly reliable power availability. Relatively high power level requirements are projected in order to support a Lunar outpost of four-to-six astronauts. The projected power output requirement is approximately twenty-five kilowatts (25 kW), but may reach one hundred kilowatts (100 kW) through modular implementation.

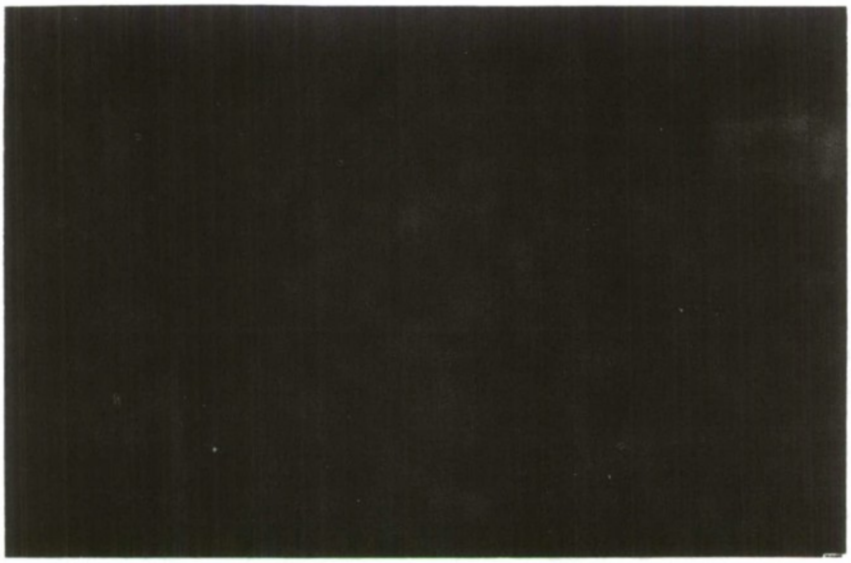
In a Lunar application, the period of darkness extends for two weeks; a Mars application presents a more manageable 12 hour night. Both applications require very high energy density power storage systems. The low insolation on Mars (43% that of Earth), coupled with reduced gravity (1/3 gravity for Mars, 1/6 gravity for the Moon), require high area power density, and low mass power generation systems of a robust design.

The Mars environment (including dust, wind, and a CO_2 atmosphere) and the Lunar environment (including dust, radiation, and wide temperature variations) will require unique design approaches in both power generation and energy storage. That design challenge will be compounded by requirements to provide intermittent operation following extended periods of inactivity.

In addition to the primary application of surface power technologies for piloted Lunar and Mars missions, surface power efforts may also be directed toward power systems in the one kilowatt (1 kW) range. Such power systems could be applied in robotic surface precursor missions, or more generally in space vehicles.

2.4.2 Technology Assessment

Regenerative fuel cell energy storage systems offer a twenty-fold (20:1) increase in specific energy over state of the art electrochemical energy storage technologies in conventional applications. In meeting the long duration storage requirements associated with Lunar applications, this advantage may be even greater. At present, regenerative fuel cell technology is at a low level of maturity. Apollo and Space Shuttle state of the art fuel cell technology is limited to a primary configuration, without regeneration, at a relatively low performance level. Increasing the operating temperature by means of increased current density will improve performance, yet the oxygen electrode catalyst - a critical component in a fuel cell stack - has not been developed to withstand lengthy high temperature (250°F) operation. Commensurate with the need for higher temperature operation are requirements for efficient and reliable thermal, gas, and liquid management technologies in the regenerative configuration. Bi-functional catalysts, if proven viable, will greatly reduce the complexity and mass of a regenerative fuel cell. In the regenerative configuration, several design concepts must be evaluated on a system level. Not only must the system performance potentials be identified and quantified, but also the technological barriers to materials compatibility, gaseous and liquid storage and transfer must be identified, quantified, and resolved.



Astronauts laying out a photovoltaic array on the surface of Mars

Space power generation via photovoltaic cells has a demonstrable specific power of about sixty watts per kilogram (60 W/kg). Recent designs are closer to one hundred and thirty watts per kilogram (130 W/kg). However, the space array concepts associated with these designs have not been developed for surface applications; they require modification - or new concepts - for evaluation of potential applications in the non-zero-gravity conditions on the Lunar and Mars surfaces. Photovoltaic cell and blanket technology advances that improve the state of the art 2 mil silicon technology will contribute significantly to the three hundred watts per kilogram (300 W/kg) photovoltaic array goal. Amorphous silicon, primarily a terrestrial technology, has been fabricated on flexible substrates and is compatible with low volume storage requirements for space applications.

Performance must be upgraded to meet surface power requirements for stability, longevity, and high-efficiency.

In general, power generation via advanced solar dynamic technologies appears to offer no mass advantage over advanced photovoltaic systems. However, the potential advantages of obtaining processed heat as a by-product, the state of maturity of solar dynamic systems, their scalability, and their packageability demand evaluation of the technology barriers peculiar to surface missions. The concentrator, heat receiver, and energy conversion system may be affected adversely by the Lunar or Mars environments as well.

Photovoltaic power generation historically has relied on electrochemical energy storage technologies. However, solar dynamic power systems have traditionally utilized thermal energy storage techniques. The latter will require modified approaches - including the use of regenerative fuel cell electrochemical energy storage - in order to meet the lengthy dark periods associated with surface operations. Replacing thermal energy storage systems with electrochemical energy storage will permit a substantial reduction in solar dynamic system mass. Hence, there is a potential five-fold (5:1) improvement in specific power for photovoltaic arrays and a three-fold (3:1) improvement for solar dynamic systems. These technological advances would result in a substantial mass savings for either a Lunar or Mars surface application.

2.4.3 Program Description

The objectives of the Surface Power Program are to develop a technology base that will support the development of space power systems capable of delivering tens of kilowatts of user power, thereby enabling future human space operations. The goal is to provide Lunar surface operations power, start-up power for a main outpost power system, piloted Mars expedition surface power, and power for Phobos and/or Deimos operations.

In cases of sustained base operations, it is anticipated that the start-up solar power system will later serve as an emergency power source for the expected nuclear power system. To accomplish these objectives, appropriate solar-based technologies will be developed to a sufficient level of technology readiness to assure confidence in the various potential mission applications. Breadboard verification of key component technologies will be followed by ground-based system verification tests of integrated power generation and energy storage technologies. It has been determined that the highest potential for successfully achieving demonstrated surface power capabilities lies in the development of power generation systems utilizing either photovoltaic or solar dynamic technologies. Due to the length of the dark period on the Lunar or Martian surfaces, both power generation approaches dictate the use of regenerative fuel cells for energy storage.

The near-term program will include systems analyses based on various mission scenarios for both Mars and Lunar surface applications; these will result in trades and concepts for potential system designs. These systems analyses will systematically develop surface power technology requirements - including critical technology barriers - that will be used to help guide subsequent program planning.

The program will address energy storage technology, with the focus on regenerative fuel cells. It will encompass several component technologies, including development of high temperature oxygen electrode catalysts in conjunction with light weight, high temperature structure

components. Gas, liquid, and thermal management innovations will be evaluated against the goal of reducing complexity while increasing life. Emerging light weight, robust tank technologies for gaseous reactant storage, an enabling technology for very high energy density regenerative fuel cells, will be evaluated. Selected ground-based breadboard evaluations will be used to validate the system performance potentials of critical components.

Efforts in amorphous silicon photovoltaic cell technology will be directed at increased efficiency, reduced mass, and improved lifetime and reliability. Blanket and interconnection technology advances will be developed. Array concepts, derived from current technologies and concepts, will be evaluated leading to key critical component fabrication and validation with promising, available, and appropriate cell and blanket technologies.

Solar dynamic power generation efforts will be limited to studies and critical technology verification as appropriate. The studies will focus on identifying technical barriers resulting from a novel systems approach in unique Lunar or Mars environments. These technical barriers to a viable solar dynamic power generation system will be evaluated in light of ongoing programs in concentrators, receivers, and energy conversion systems.

Deliverables

PHASE I. Promising technologies - as well as systems to be pursued - will be guided by system and mission analysis to be completed in the first eighteen months of the program. By mid-1991, promising energy storage component technologies will be identified with breadboard verification completed by 1993. Prototype blanket technology will be verified by 1994. Key prototype array components under fabrication by 1993 will reflect promising design concepts that have been previously evaluated.

PHASE II. During Phase II, and by the mid- to late- 1990s, a prototype testbed power system using outputs from Phase I of the program will be fabricated. Power generating and energy storage systems will be built and integrated into power systems and tested to verify design concepts for future flight hardware fabrication.

2.4.4 Organization and Management

Work Breakdown Structure. The work breakdown structure (WBS) is directed along technology discipline lines, with integration and coordination functions performed by the Power Technology Division at the Lewis Research Center (LeRC). Figure 2-4 provides a top-level WBS for the program.

Management Structure. The overall program will be managed by a Program Manager in the OAST Energy, Power, and Propulsion Division (RP).

Technology Project management responsibility will reside in the Power Systems Integration Office at LeRC. The program manager will have the responsibility of coordinating with other programs and Pathfinder elements to avoid duplication of efforts and to ensure that all technologies are being adequately addressed. The Technology Project Manager will have responsibility for leading the development of a technology project plan and for the implementation of the project throughout its duration. All participating centers will be responsible to the Technology Project Manager for all matters, including resources, project responsibilities, and administrative duties pertaining to reporting, schedule,

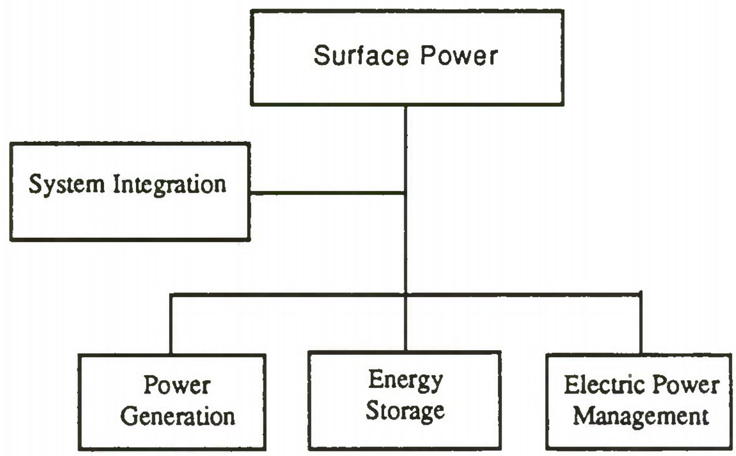


Figure 2-4
Work breakdown structure for the Pathfinder Surface Power Technology Project

and milestones. The project manager will also have the responsibility of insuring that specific technology efforts are coordinated through matrixed responsibilities in each technology discipline. The project manager will utilize discipline branches within the LeRC Technology Power Division as well as expertise available in the LeRC Advanced Space Analysis Office, the Jet Propulsion Laboratory, the Johnson Space Center, and other NASA Centers as appropriate.

LeRC will have responsibility for leading the development of a Technology Project Plan and for administration of the plan throughout the program. All participating centers will be responsible to the program manager in RP for all questions involving resources and program responsibility. They will be responsible to the lead center in administrative matters pertaining to reporting, scheduling and milestones.

Program Coordination. The Surface Power element of Pathfinder will be coordinated with other appropriate programs established in the OAST Space Research and Technology (R&T) Base program, in the Civil Space Technology Initiative (CSTI), and with other elements of Pathfinder. Mission scenario developments will be coordinated with the Office of Exploration. Technical advances realized by the Space Station program and non-NASA space programs will be incorporated into overall program planning as appropriate.

Resources. Resource requirements for fiscal years 1989 through 1993 are approximately \$36.5 million. The funding allocation for FY 1989 is \$1.5 million.

Section 2.5
Photonics

2.5.1 Technology Requirements

NASA'S planning for the future exploration of the solar system includes missions requiring both extremely powerful information processing systems, and computers and networks with a high degree of fault tolerance. The emerging technology of photonics can play a key role in meeting these needs. The Pathfinder Photonics program is aimed at the developing of key enabling systems and device technologies that have the most leverage on future NASA needs.

The four leadership initiatives in the Sally Ride report "Leadership and America's Future in Space" impose a variety of taxing requirements on information acquisition and processing capabilities in space. For instance, the control and communication systems of transport vehicles carrying humans, or of Lunar or Martian habitats, must be extremely reliable. The functions invoked to achieve fault tolerance exact a high overhead in hardware and software which impacts negatively on processing and communication rates. For human transport vehicles and habitats for Pathfinder, control and communication systems using conventional electronics and cabling cannot provide the necessary systems performance within the needed weight and power margins. Fiber optic networks with compatible computing and sensing nodes and in situ integrated optic sensors will enable the necessary overhead to be accommodated while substantially reducing system power, mass and volume, and increasing processing and transmission capacities by several orders of magnitude.

NASA also has a number of needs for processing where a very high degree of parallelism is involved, such as two dimensional image processing. Extraction of information from an optical image, laser ranging data, and multi-spectral data is needed to facilitate the intelligent exploration of the surface of both the Moon and Mars with a robot roving vehicle able to discover sites of potential mineralization, recognize anomalous rocks and other potential surface samples, and negotiate rapid traverses of the surface without hazard. Similar very fast information extraction is critical to facilitate the last few minutes of powered descent of a robot lander to a desired landing spot identified from orbital imagery. In these cases, correlations and feature extractions must be implemented over an entire image, and the capability of optical processing to execute images in a million parallel channels is extremely powerful. Additionally, a planetary rover/orbiter communication system may demand phased array radar with 100's to 1000's of transmitter chips. This may be difficult to do in space without the development of photonic controls.

2.5.2 Technology Assessment

At present, optical processing systems have achieved very limited application in ground and space systems. They have been used for processing synthetic aperture radar data on the ground for NASA space missions, and they are being planned or developed for high-speed RF spectrum analyzers for both ground and space use. Photonics does have the potential, however, to surpass electronics in important areas of computation. The high throughput of analog photonic data processing reflects the enormous information capacity of light waves and the inherently concurrent nature of wavefront operations. Photonic flight systems are expected to be more fault tolerant and reliable than comparable electronic systems

because they will have fewer discrete active components and physical interconnections, and architectures inherently more resistant to single-component failures. Photonics is still immature as a technology for NASA flight systems. However the performance of matrix multiplications, correlations, convolutions, broad-band spectrum analysis, and other basic mathematical transformations has been demonstrated in the laboratory and in prototype applications, and research is rapidly broadening the scope and power of these operations. The potential to package optical information systems in forms compact and robust enough for qualification and deployment has been established. The challenge for NASA is to develop the specialized processing algorithms, the fault-tolerant architectures, and the physical components needed to focus the technology on future flight-system requirements.

The Photonics Program will address future mission requirements that do not appear to be fulfilled by current information processing capabilities. Present high-capacity, fault tolerantly fiber optic networks employ interface devices to transfer the optical signal to an electronic signal, and back again. This conversion process causes a data bottleneck to occur at the network nodes. By processing the information optically, the light would be allowed to continue undeterred unless a fault were detected. Current in situ sensors for spacecraft typically do not fulfill the sensitivity and lifetime requirements of planetary missions. Current designs of electronically controlled phased array antennas appear to be too bulky and heavy for space-based use. Finally, many image processing calculations needed for both autonomous landers and rovers are so computation intensive as to require large earthbound computers.

2.5.3 Program Description

The strategy of the program consists of focusing the technology effort in the first few years of the program through a combination of breadboard testing and systems studies (to be performed in part by the Office of Exploration) that will result in a few systems that will be developed to the prototype stage in order to compare their performance with more traditional electronic systems. The Photonics program will encompass both systems and device activities which are at present at varying stages of technology readiness. The program includes basic research in photonic devices which will be focused on the class of devices known as SLMs and photonics system developments which will include initial demonstrations with existing SLM technologies, followed by demonstrations with the new SLM technologies during later phases of the program.

The Pathfinder Photonics Program will develop those hybrid photonic/electronic technologies that have the potential to be better than all-electronic systems for solving some of the mission requirements for NASA's future planetary missions. Specific objectives of the program are as follows:

1) To develop fault tolerant, high data rate networks for space systems applications. These applications include autonomous spacecraft, interplanetary transport vehicles and planetary and lunar habitats. Goals include the development of photonic nodes and in situ integrated optical sensors.

2) To enable safe traverses by a planetary rover at higher speeds and requiring less power than competitive all-electronic systems through the use of optical pattern recognition. The program will provide a capability for the high speed acquisition and analysis of reconnaissance data acquired by a planetary rover through the

use of optical multi-spectral processors. Additionally, the program will provide Ka-band phased array radar for rover/orbiter communication at potentially much lower mass than competitive electronic systems through the use of fiber optic control.

3) To enable the electronic vision systems needed for automated landing on planetary surfaces to have up to three orders of magnitude reduction in processing requirements through the use of a photonic preprocessor. Critical technologies will be developed in photonic sensors, integrated optical switches, fiber optic control of MMIC chips, and image processing architectures. Selected spatial light modulators (SLM) will be developed to enhance the processing speed of the above systems during later phases of the program. Many of these tasks will leverage photonics work currently being accomplished by the DoD, industry and universities. The ultimate program objective is to test these systems with mission simulated data and testbeds when available.

The program begins with breadboard testing of a variety of hybrid photonic/electronic technologies that have the potential to fulfill mission requirements as developed by mission analyses. The technologies fall roughly into three categories: fault tolerant networks which include photonics switches and sensors; SLMs which include semiconductor and other materials and device development; and optical processors which utilize light's two-dimensional, parallel, non-interacting propagation capabilities for optical computing. By the end of 1990 the three thrust leaders will review their efforts in order to downselect the technologies mentioned above to those few that have the most potential to fulfill mission requirements.

In the early 1990s, the United States will make a decision on which mission to pursue. That decision will be based partially on which technologies are mature enough at that time to support that mission. For this reason, the Photonics program will continue brassboard development of those systems that were downselected in 1990, and will perform an evaluation of their performance in 1992 in order to support NASA's decision. In the Fault Tolerant Networks thrust this will involve the development of those photonic architectures, devices and sensors necessary to support the goal of building a network that can withstand three faults while having a data throughput of up to 1000 Mbps. In the Autonomous Planetary Systems thrust this will involve the development of a variety of optical processors.

Vision systems will be developed for both autonomous lander and autonomous rover applications. Initial testing will be done using simulated data in order to compare the optical computers' performance with that of electronic computers. An optically controlled phased-array antenna will be developed for rover/orbiter communication. Similarly, in the Spatial Light Modulator thrust, those few SLMs that were downselected in 1990 will be developed to mature, prototype devices through the year 1995.

Throughout the late 1990's, focused development and final testbed evaluations will occur utilizing updated mission studies. The SLM development will have resulted in good candidates for insertion into the vision and node processing systems, thus dramatically increasing processing capability. The Fault Tolerant Network thrust will have maximally leveraged the CSTI/Data element work in optical switches, as well as DARPA's photonics program to build space-qualifiable, high-capacity, fault-tolerant networks including in-situ sensors that have been tested in an integrated data systems testbed. The Autonomous Planetary Systems thrust, together with the Autonomous Lander and

Rover elements of Pathfinder, will have coordinated development of space-qualifiable, photonics/electronics vision system prototypes which will undergo final evaluation on the rover and lander testbeds. By 1998, the systems will be developed into prototypes and coordinated with other Pathfinder demonstrations for final verification.

2.5.4 Organization and Management

Work Breakdown Structure. The program is organized into three thrust areas, with specific integrating, or cross cutting tasks (see Figure 2-5). A continuing program of systems studies will be pursued to guide the overall direction of the effort. In the second year of the program, a downselect of tasks will be undertaken and a limited number of tasks will be selected for prototype development.

Management Structure. The Photonics Program is managed by the Photonics program manager in the OAST Information Sciences and Human Factors Division (Code RC). Responsibility for Center assignments, project plan approval and funding allocation will remain at Headquarters Code RC. Program advice and coordination is provided by the Photonics Working Group, which is made up of representatives from the NASA Centers and those NASA Offices that would be potential users of the technology.

Project planning, integration and reporting is performed by the NASA Center thrust leaders and the Photonics Working Group co-chairperson. Quarterly project reports will be submitted to OAST tracking progress against Level 1 schedules and identifying any problems, issues or

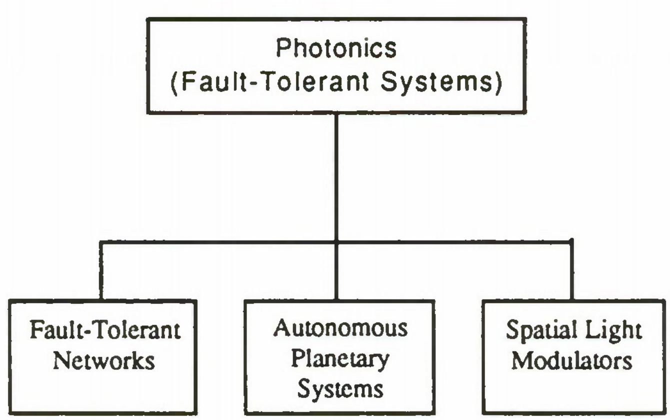


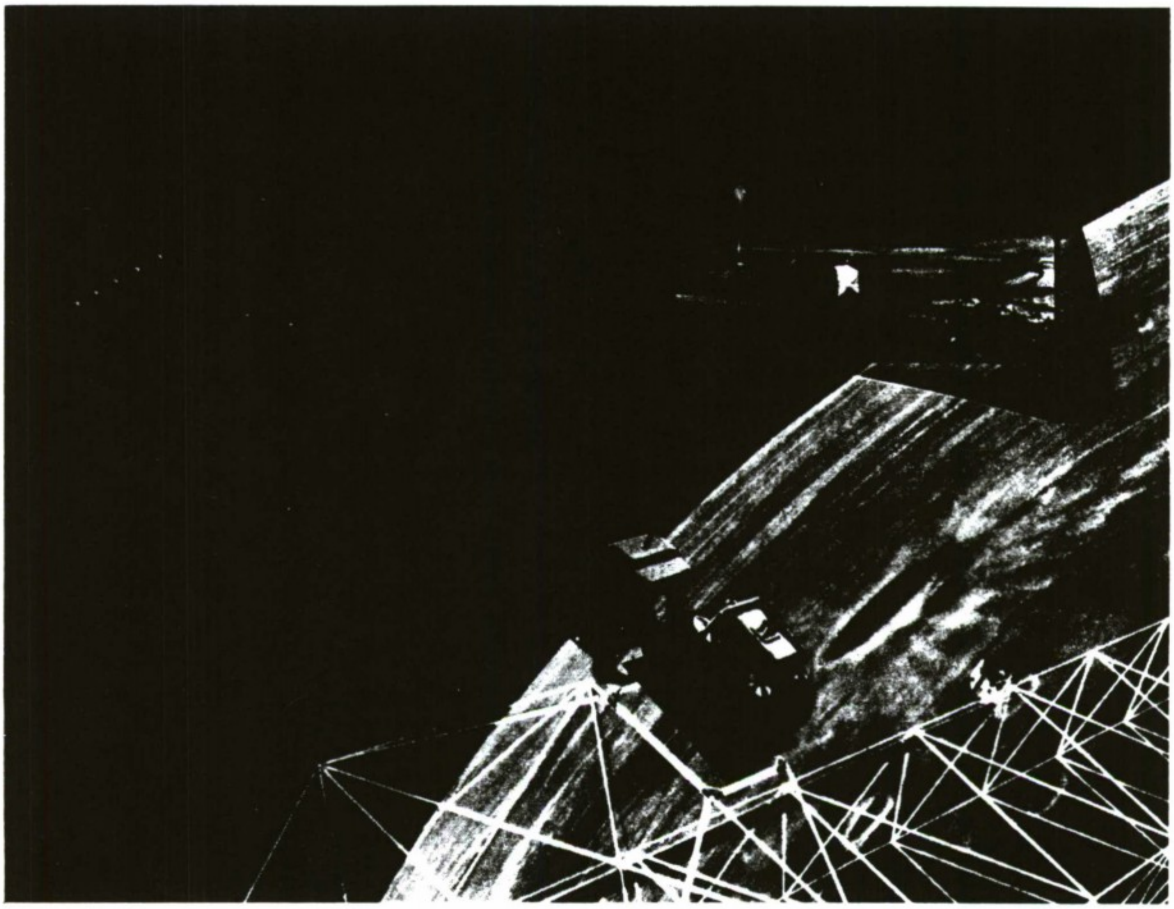
Figure 2-5
Work breakdown structure for the Pathfinder Photonics (Fault-Tolerant Systems) Technology Project

significant accomplishments. NASA Centers will be designated to implement project elements.

Program Coordination. The program was originally formulated with the guidance of the Ad Hoc Review Team on Photonics subcommittee of the OAST Space Systems Technology Advisory Committee. This Review Team facilitated the coordination of the NASA program with DARPA, Air Force, Army, Universities and Industry. As well, this program will be coordinated with those elements of Pathfinder which are customers for the technology including Planetary Rover, Sample Acquisition, Analysis and Preservation, Autonomous Rendezvous and Docking, and Autonomous Lander. In addition to the internal coordination in Pathfinder, interaction will also take place with the representatives of science instrument users in the Office of Space Science and Applications and the Office of Exploration. Finally, the Photonics program will leverage ongoing work in the CSTI Data program, and the Research and Technology base Photonics program.

Resources. Resource Requirements for fiscal years 1989 through 1993 for the Photonics Technology Project are approximately $32 million.

Pathfinder.



Chapter 3
In-Space Operations

The objective of the In-Space Operations program area is to develop a wide assortment of key technologies that will enable or significantly enhance high-leverage space operational capabilities in support of solar system exploration.

Advances in our capabilities for in-space operations has been a major objective of the civil space program since the 1960's. For example, a significant part of the Gemini Program's objectives was the development and demonstration of orbital rendezvous and docking - a key capability for the Apollo missions to the Moon.

The Space Shuttle provided a major augmentation of U.S. in-space operations capabilities. Shuttle has demonstrated critically-needed operations - including retrieval and repair of spacecraft in space. As well as providing a platform for extended technology demonstrations, including in-space construction techniques, space power systems, and microgravity fluids research.

The Space Station will provide still another major enhancement of our capabilities by providing a permanent in-space facility. Operations will include spacecraft servicing, microgravity research, and staging of future missions. In fact, each stage in the history of the civil space program has been dependent upon technological advances in the area of in-space operations.

Pathfinder In-Space Operations efforts consist of six technology projects: (1) Autonomous Rendezvous & Docking, (2) In-Space Assembly and Construction, (3) Cryogenic Fluid Depot, (4) Space Nuclear Power, (5) Resource Processing Pilot Plant, and (6) Optical Communications.

Each of these is described in some detail in

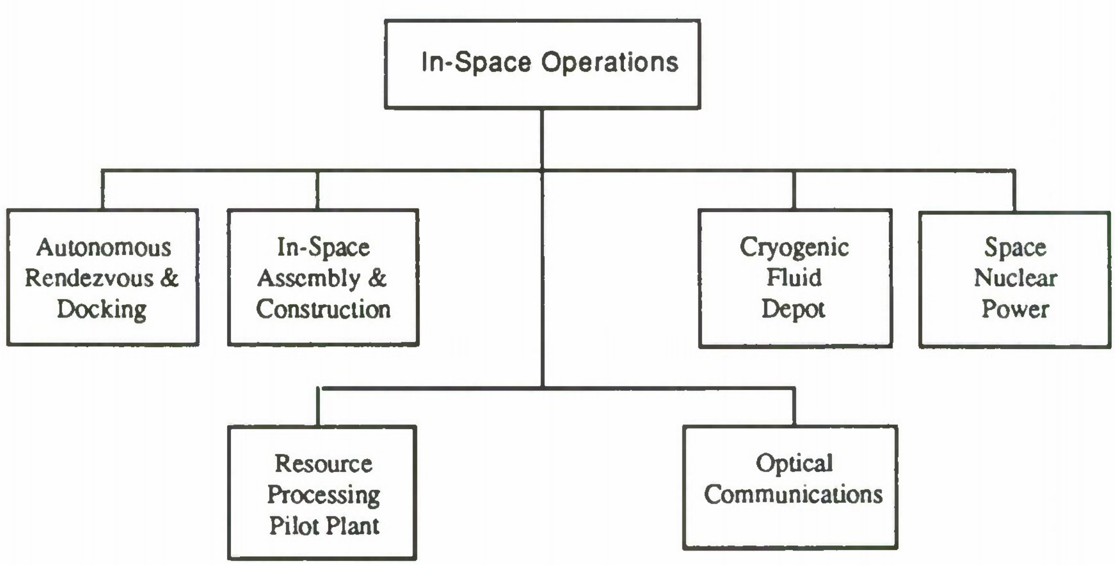


Figure 3
Work breakdown structure for the Pathfinder In-Space Operations Program Area

the subsections which follow

Section 3.1
Autonomous Rendezvous & Docking

3.1.1 Technology Requirements

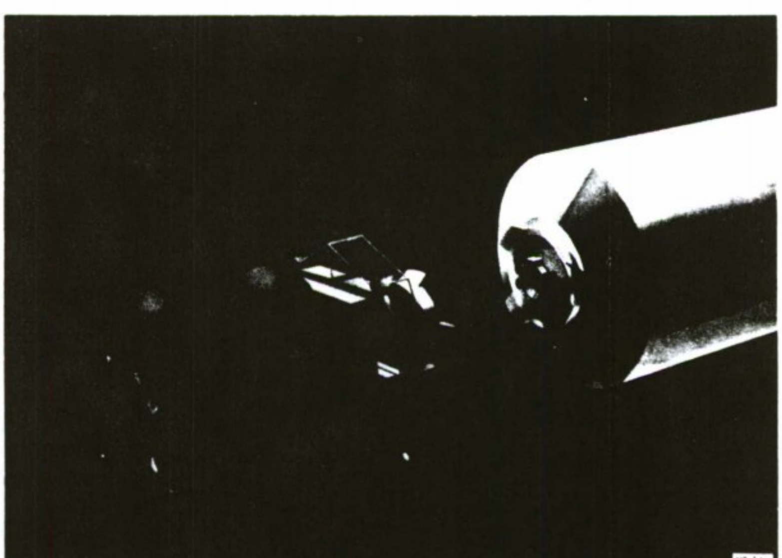
NASA's planning for the future exploration of the solar system includes both piloted and robotic missions to the Moon and Mars. As was true with Apollo, these missions will require the use of smaller vehicles to go to and from the lunar or planetary surface. Because of round-trip-light-time (RTLT) delays in deep space communications, real-time Earth-based control of these vehicles will be impossible.

The capability for autonomous rendezvous and docking with the mission elements remaining in orbit will be required for both piloted and robotic missions.

The specific technology requirements include the development of sensors and mechanisms, trajectory control requirements and techniques for operations in Lunar and planetary orbits, and associated integrated guidance, navigation, and control algorithms such as automatic selection/execution/recovery techniques and multivehicle cooperative control.

Sensors are required to provide long- and short- range tracking and relative navigation from several hundred kilometers down to the contact point of docking. Sensor technologies are driven by performance requirements for extended service life in hostile environments with long periods of dormancy. Docking mechanisms will support robotic vehicle operations.

Trajectory control techniques will differ from current Earth-orbit, piloted vehicle operations in that many of the constraints, such as lighting, ground tracking coverage, and continuous space-to-ground communications will not be applicable. Instead, trajectories must be designed to maximize the reliability of rendezvous in Lunar and planetary orbits.



A fuel-carrying vehicle docks autonomously with a future space station

Integrated guidance, navigation, and control (GN&C) designs must provide the performance, reliability, autonomy, and automation required for autonomous rendezvous and docking in Lunar and planetary orbits. Major design challenges include automatic selection, execution, and recovery techniques and multivehicle cooperative control.

Expert system technologies are applicable.

3.1.2 Technology Assessment

At present, the United States has not demonstrated an autonomous rendezvous and docking capability. Current capabilities require extensive ground and flight crew participation. The rendezvous phase of a mission is based on significant ground tracking of the spacecraft. The docking phase requires the control of an observer on one of the spacecraft. This degree of observation will not be available for robotic Mars vehicles and the communication time delays will preclude control through teleoperation from ground-based operations centers. The implementation of autonomous rendezvous and docking will require the development of several critical technologies.

Sensors for long- and short- range navigation must be developed which provide the required performance, meet constraints on mass, volume, and power, and can withstand the hostile environment and long periods of dormancy associated with planetary exploration mission. The onboard rendezvous sensors on the Space Shuttle (star tracker and rendezvous radar) provide relatively poor performance and require careful crew monitoring. They are totally inadequate for ranges less than 90 feet. The radars being considered for the Orbital Maneuvering Vehicle (OMV) will also be ineffective at very close ranges. No suitable long-range radars that meet the power, mass, and performance requirements of a Mars rover and sample return mission are available.

A prototype laser docking sensor is being developed for a flight experiment in FY 1991. This system shows much promise for ranges from zero to greater than three miles. Further work is needed to study extensions of the range of this sensor and reducing its power, mass, and volume requirements. Other candidate sensors such as millimeter-wave radar and robotic video image recognition systems require further evaluation and technology development.

GN&C algorithms for the rendezvous problem are well understood, but work is required to focus the designs on mission constraints unique to solar system exploration scenarios. Current designs focus on constraints associated with piloted vehicles and include lighting conditions and continuous space-to-ground communications. solar system exploration missions will not necessarily be subject to these constraints, but require an emphasis on reliability of the rendezvous and docking operations. Cooperative control and automatic selection, execution, and recovery are major design challenges.

Docking mechanisms for piloted vehicles have been or are being developed which should suffice for piloted solar system exploration vehicles. However, unique mechanisms will have to be developed for small, robotic vehicles such as the "Mars Ascent Vehicle" and "Mars Orbit Vehicle" that are being planned as elements of a robotic Mars mission. In addition, the docking mechanisms for solar system exploration missions will require extended service life in hostile environments with long periods of dormancy, high system reliability, and high levels of autonomy for robotic vehicle operations. The mechanisms will be subject to severe power and mass restrictions.

3.1.3 Program Description

The objectives of this program element are the development and demonstration of the enabling and enhancing hardware and software technologies and technical approaches for autonomous/automated rendezvous and docking to support Lunar

and Mars missions. Specifically, the constraints and unique requirements will be established for the various types of planetary missions that are envisioned. Using these requirements and constraints as guidelines, long- and short- range sensors will be developed for rendezvous and docking. Algorithms will be developed for both long- and short- range phases of the rendezvous problem and will be demonstrated in computer simulations and then in flat floor testbeds. Finally, flight tests of the rendezvous and docking concepts developed under this program will be planned.

For the several selected solar system exploration mission scenarios and corresponding vehicle configurations, coordinated systems-level rendezvous and docking requirements will be defined. The performance requirements on the autonomous rendezvous and docking hardware and software will be established.

The hardware and software technologies needed to meet those requirements will be identified and current technologies will be assessed for applicability. The need for new technologies will be defined with an emphasis on sensors for long- and short-range tracking and relative navigation. A decision will be made as to whether a single sensor or a suite of sensors will most efficiently meet long- and short- range performance requirements for Lunar and planetary missions.

Trajectory control requirements and techniques for autonomous rendezvous and docking will be defined. Candidate GN&C designs will be developed to implement these capabilities. Six and twelve degree of freedom (DoF) simulations will be developed and used for performance, dispersion, and sensitivity analyses and trade studies of these designs.

Results of these evaluation will be used to establish the specifications for prototype sensors. Prototype sensors and hardware and software emulations will be developed and incorporated into testbed proof-of-concept demonstrations. The requirements and benefits of technology flight demonstrations will be evaluated.

Deliverables

The requirements and mission constraints for autonomous rendezvous and docking for the various planetary missions will be established during the first year of the program. In addition, work will begin on the GN&C concepts that are most appropriate for this problem and on sensors that are required for the long- and short-range parts of the problem. There will be two sets of demonstrations of the technology based on near- and far- term capabilities.

The near-term demonstrations will begin in the second year of the program with computer simulations of GN&C concepts and with the flight test of the Laser Docking Sensor (which is already scheduled and is independent of this Pathfinder effort). High fidelity simulations will begin in the third year of the program and will transition to flat floor demonstration the following year.

The more advanced sensors will be demonstrated in the fifth year and will be added to the computer simulations and then to the flat floor testbeds by the seventh year of work. Flight demonstrations must be carried out in orbit and are beyond the currently project funding level of this element of Pathfinder. This program will carry the technology to a stage where it is ready for flight demonstration.

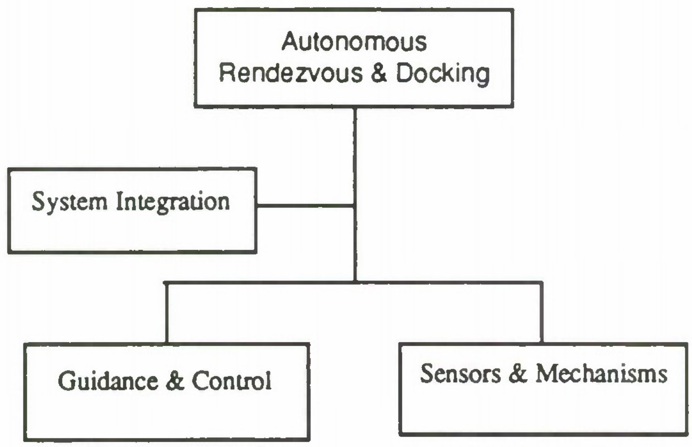


Figure 3-1
Work breakdown structure for the Pathfinder Autonomous Rendezvous & Docking Technology Project

3.1.4 Organization and Management

Work Breakdown Structure. The work breakdown structure (WBS) is directed along technology discipline lines. It consists of three major areas: systems integration, guidance and control, and sensors & mechanisms. Figure 3-1 provides a preliminary WBS for the program.

Management Structure. The overall program will be managed by a Program Manager in the OAST Information Sciences and Human Factors Division (RC). Responsibility for Center assignments, project plan approval and funding allocation will remain at OAST/RC. Program advice and coordination will be provided by the Autonomous Rendezvous and Docking Working Group, which is made up of representatives from the NASA Centers and those NASA Offices that would be potential users of this technology. Technology Project planning, integration, and reporting will be performed by the NASA Center coordinator. Quarterly project reports will be submitted to the OAST Program Manager tracking progress against Level 1 schedules and identifying any problems, issues, or significant accomplishments.

Program Coordination. The Autonomous Rendezvous and Docking Program will be coordinated with the following NASA activities: the new initiative mission definition studies being conducted by the Office of Exploration (OEXP), the development of high capacity, flight qualified computers conducted by OAST, and the Mars Observer mission and Mars Rover/Sample Return (MRSR) study being conducted by the Office of Space Science and Applications (OSSA). The effort will also be coordinated with planning within the Office of Space Flight (OSF).

Resources. Projected resource requirements for the Autonomous Rendezvous & Docking Technology Project for fiscal years 1989 through 1993 are approximately $15 million. The resource allocation for FY 1989 will be $1 million.

Section 3.2 *In-Space Assembly and Construction*

3.2.1 Technology Requirements

Future space missions to exploit low Earth orbit, build an outpost on the moon or land on Mars will all likely involve large space structures that cannot be placed in orbit by a single launch vehicle. The most notable structure at the present time is the Space Station, which will be fully assembled in space. It will be the first large permanent base placed in orbit and may also serve as a base for assembling and servicing other large structures, including earth observing fee-flyer platforms, proposed large scientific instruments such as a lightweight 20-meter submillimeter wavelength telescope and other large vehicles.

A lunar outpost is likely to utilize a large transfer vehicle to transport material between the moon and low Earth orbit and a piloted Mars mission will require a very large vehicle on the order of a thousand tons. Both vehicles will also likely use large, bulky aerobrakes up to 100 feet across (possibly larger) and will be built, out-fitted (e.g., the installation of utilities) and serviced at the Space Station or at a nearby "garage". Any such vehicle would also be intended for extensive reuse and thus, need to be refurbished or repaired on-orbit. Unlike the space station, which will be largely built by hand, technology must be developed to enable the on-orbit assembly and construction of these systems and design methodology established to enable large space structures to be "designed-for-construction"

High-load carrying mechanisms could be used to simplify the design and assembly of heavily loaded, modular vehicles that use aerobraking, replaceable fuel tanks or engines. These mechanisms could absorb heavy vibrational loads from rocket motors and construct more lightly loaded, but massive, orbiting structures (such as a fuel depot) by requiring only a few attachment points. Advanced mechanisms could also enable the development of very large or heavily loaded deployable structures and simplify installation of utilities. Large area welding/bonding would enable construction of elements such as, large habitats and work spaces, fuel tanks, aerobrakes and strong, lightweight permanent joints between structural members.

Precise telerobotic manipulation and control of large structural components is needed to bring them together for mechanical joining and to hold them accurately in place for processing a permanent joint. This must be done within a physical framework designed to facilitate space construction, and furthermore, by coupling general assembly and construction methods with telerobotic methods large complicated structures could be built, operated and maintained with minimal EVA to reduce cost and enhance safety.

3.2.2 Technology Assessment

Currently, the capability to build structures of any kind in space is very primitive. Our experience is limited to a few simple experiments. Recently, two truss structures were hand assembled from the shuttle bay

during STS-61B[1]. During the first experiment, a 13.7 meter, 10-bay truss beam was constructed from 93 (1.4-meter and 2.0-meter) struts. The value of this experiment was to test the feasibility of erecting the primary truss for the Space Station. The second experiment involved repeated assembly and disassembly of a single bay of a larger more bulky truss structure. Neither of these experiments addressed permanent joining, and all structural elements were very light and easily controlled by hand manipulation.

We have no operational experience in permanently joining (e.g. welding or bonding) structures in space. The few Skylab experiments that were performed did demonstrate feasibility, but they did not alleviate concerns that gravity influences the convective processes in the weld bead. The Soviets have used electron beam welding to build a truss in space. However, the quality of construction is not known. Bonding methods compatible with a space environment have been proposed for Space Station, but these are for relatively lightly loaded applications such as repairing a hole in a Space Station module.

Masses have been manipulated at the end of the shuttle remote manipulator system (RMS). All instances involved satellites weighing much less than the shuttle, which provided a comparatively stable base, and required extensive ground simulation in advance. At no time were two masses brought together and held precisely in place, as will be required to build a large space structure. We have precisely manipulated large masses and joined them during docking maneuvers, but such operations are not practical for general purpose construction methods. Currently, we can simulate manipulation in the laboratory using "rigid" arms but not ones with a high degree of flexibility or with masses representative of large-scale assembly and construction operations.

1. Nov. 29 - Dec. 3, 1985

Based on current programs, by 1993, our ability to build space structures will be at the level of Space Station technology. Large, erectable truss beams will be designed for hand and robotic assembly, but this will involve relatively small lightweight elements. Remote manipulation will be developed to place larger objects close enough to be mated to specially designed attachments. No large planar or volumetric structures will be built, though an OTV hanger may eventually be added to the Space Station. The Department of Defense also has projects that may involve in-space construction, but they presently rely on NASA to develop construction technology.

3.2.3 Program Description

The Pathfinder In-Space Assembly and Construction program activity will develop the basic technology required to construct large, massive structures and complex vehicles in space. One objective is to define and develop methodologies for constructing generic spacecraft components (such as aerobrakes, backbone trusses, pressurized modules, etc.) that can be applied to many different missions. This will lead to spacecraft which have assembly and construction requirements integrally incorporated into their design. The second objective is to develop the processes (welding, bonding, and mechanically attaching) required to join components in space. Accomplishing this objective will require that concepts for specialized holding fixtures and robot end effecters be developed. Methods for testing and verifying joint integrity must be developed in concert. The third objective is to develop the ability to manipulate and position large massive vehicle components precisely so that they can be permanently joined. Concepts, such as transporters,

space cranes and assembly fixtures, will be fabricated and demonstrated to achieve this objective. The fourth objective is to define the facility layout and infrastructure which is required to support constructing large spacecraft in space. A blueprint is envisioned for a facility having a high degree of construction flexibility, adaptability, autonomy, and commonality.

To accomplish this in the most general context is beyond the current capability of the program. As such, the program will be directed toward those areas which are most critical to this goal. It will not focus on designing or developing any specific structural designs (e.g. aerobrakes, transfer vehicles, scientific instruments or large platforms), but will identify and develop common critical elements of in-space assembly and construction within these systems that require a strong focused technical program. However, focused applications will be selected to guide the development process.

As previously discussed, the critical areas identified at this time are associated with building large structures in low earth orbit. (through this applies to structures to orbit Mars or the moon as well). By focusing on the enabling technologies, and not specific systems, the program will have the flexibility to meet changing demands and will provide mission planners and systems designers with a broad range of design options. To assure that key issues are being addressed systems studies (in cooperation with the Office of Exploration) will be conducted in parallel with technology development. These studies will focus on assessing the characteristics of large advanced space structures, such as rotating systems for artificial gravity, that may be critical to NASA long range goals and objectives and whether the current program will enable them to be built. A key aspect of this program will be to assure that significant advances in deliverable technology are achieved.

The early part of the program will concentrate on evaluating and developing concepts (including possible hardware development) for general assembly and construction and for precise manipulation of large masses. All cases will emphasize telerobotic operation. This will lead a set of selected concepts and methods to be developed and a set of focused applications to guide the development process. An additional product of this part of the program will be design methodology tailored for space-based construction and the definition of a physical infrastructure (scaffolding, cranes, transporters, etc.) to support construction operations.

The latter part of the program (after the first five years) will integrate methods for construction and manipulation into unified robotic construction methods. It will also place more emphasis on operational autonomy, efficiency and reliability (quality assurance). This process will also require methods by which this technology can be, in principle, validated on earth without extensive space experiments. During this development phase a space experiment may be conducted, if required, though it is not currently being planned.

Deliverables

PHASE I. By the early 1990's, methods for producing high-load carrying mechanical joints/mechanisms and strong permanent joints (e.g. welded/bonded) will be developed for general large-scale construction and demonstrated to be compatible with telerobotic operations. A concept to manipulate large masses telerobotically and precisely using a "space crane" (non-rigid) will be developed. This will be done in a testbed environment using a selected focus as a means for general development and validation. Also, ad-

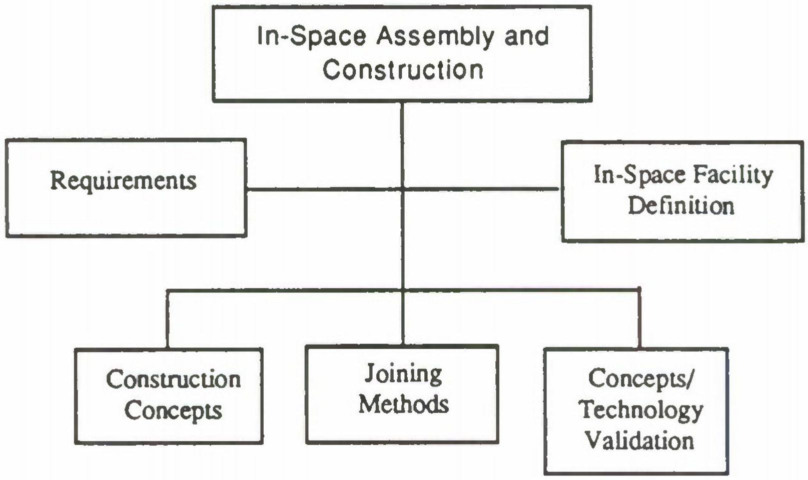


Figure 3-2
Work breakdown structure for the Pathfinder In-Space Assembly and Construction Technology Project

vanced "design-for-construction" methods will be established and a comprehensive space-based construction system (e.g. support frames, manipulators, etc.) will be defined. This will allow mission planners broad options to develop concepts for a permanent space infrastructure of stations, platforms and vehicles with a high degree of confidence that their proposed structures can be efficiently built and serviced.

PHASE II. By the late 1990's, basic methods for joining/bonding and precise manipulation will be integrated to develop general purpose telerobotic methods for automated assembly and construction of large space structures. This phase of the program will also utilize the results from fundamental research in robotics and sensor technology to provide local autonomy to the methods such as aligning a mechanism or following a weld line. Laboratory hardware will be developed along with operational procedures to validate all selected assembly and construction concepts. A part of this process will be the development of ground-based test methods to simulate in-space operations. A flight experiment may be conducted during this phase of development.

3.2.4 Organization and Management

Work Breakdown Structure. The element work breakdown structure will consist of five main tasks. The first will define basic requirements for in-space assembly and construction. Factors such as, size, shape, loading, and reuse will be used to identify basic structural elements (e.g. tension and compression members, permanent and temporary joints, utilities, etc.) and commonality among different systems (e.g. aerobrakes, pressurized habitats, large fuel tanks, etc.). The second task will focus on

construction concepts including methods for precise manipulation and control of large components, specialized telerobotic operations and hardware concepts and overall in-space assembly and construction procedures. The third task will develop the basic joining methods and any specialized supporting hardware concepts (e.g. sensors, mechanisms, etc.) to enable telerobotic operations. Mechanical joining methods and permanent joining methods (e.g. welding and bonding) will be developed. A testbed will be developed under the fourth task and focused applications performed to guide development of integrated methods and to validate technology developed under the other three tasks. Advanced test methods will also be developed for ground-simulation of in-space assembly and construction methods. The fifth task will define an in-space construction system to enable large-scale operations. This task will also develop computer simulations of assembly and construction procedures and any required ground-based test methods to approximate in-space operations.

Figure 3-2 provides a preliminary work breakdown structure (WBS) for the program.

Management Structure. The overall program will be managed by a program manager assigned from the OAST Materials and Structures Division (RM), with a technical advisor for telerobotics designated from the OAST Information Sciences and Human Factors Division (RC). During the initial planning phase, an advisory committee will be formed consisting of selected technical specialists from field centers, RM, RC, the OAST Space Directorate (RS) and a mission representative from the Office of Exploration (Z). The committee will be chaired by RM and remain in place for the duration of the program, with membership adjusted as required. (Once the program is in place, members outside of NASA may be added.) This committee will be charged with evaluating the technical goals, objectives, and progress of the program and recommend changes if deemed necessary.

The lead center for this element of Pathfinder will be LaRC. This center will have responsibility for leading the development of the program plan and for the administration of the plan throughout the program. A program coordinator at LaRC will be assigned for this purpose. JSC and MSFC are currently designated as primary participating centers for program development and implementation. They will be responsible to the program manager in RM for all areas involving resources and program responsibility. They will be responsible to the lead center in administrative matters pertaining to reporting, scheduling, and milestones.

A detailed five year program plan (with less detailed extensions to ten years) will be developed before the program begins. This will be accomplished cooperatively among the participating NASA centers and OAST. The lead center will be responsible for coordinating this activity and producing the final document. The authority to resolve conflicts will reside with the OAST program manager. This document will exclusively determine program content, center responsibilities, resource allocation and milestones. The program will be formally reviewed each year. During these reviews there will be opportunity for other centers to participate in the program in particular areas of expertise. As such, the program plan will be modified as required and will be extended to cover the next five years.

Program Coordination. The In-Space Assembly and Construction Technology Project of Pathfinder will be coordinated with the on-going robotics programs in

CSTI, the Base R&T and Space Station. An objective of this element is to benefit from these activities, not to compete with them or to duplicate their efforts.

Coordination will also, be maintained with programs to develop advanced structural concepts within the Materials and Structures Division of OAST. These activities often focus on concepts for specific classes of systems which can benefit from Pathfinder technology and which, in turn, can provide greater insight into the nature of advanced space structures.

An important activity within NASA is the planning and advocacy of long range missions and technology efforts to support those missions. As such, close cooperation will be maintained with the Office of Exploration (and to the extent required the Office of Space Science and Applications).

Overall coordination with the other elements of Pathfinder, the OAST space program in general, and overall NASA space plans and policy will maintained through the OAST, Directorate for Space. In particular, the Out-Reach space experiments program has accepted proposals to define three space welding experiments. If later accepted for development they would be candidates for shuttle flight experiments. As such, they would provide strong support to this element of Pathfinder and will be considered during program planning.

Resources. Project resource requirements for the fiscal years 1989 through 1993 are approximately $30 million. The resource allocation for FY 1989 is $1 million.

Section 3.3
Cryogenic Fluid Depot

3.3.1 Technology Requirements

Current planning for future U.S. missions includes spacecraft that will be launched into low Earth orbit (LEO) with limited, or no, operationally-required cryogenic fluids on-board (for example, fuels - such as liquid hydrogen and liquid oxygen, or coolants - such as liquid nitrogen). Such a launch scenario may be preferred for a variety of reasons; these include launched mass reduction, thermal performance optimization , and risk reduction. Cryogenic fluids for these spacecraft will be transported to orbit separately, and then transferred to the user-spacecraft on-orbit for operations. Periodic resupply of cryogens may also be required in order to extend the useful life of this class of spacecraft - or of selected payloads accommodated on the U.S. Space Station.

A variety of future U.S. space missions and operations will depend upon the availability of on-orbit cryogen supplies. The viability of a space-based Space Transfer Vehicle (STV), for example, will require on-orbit cryogen resupply. Also, nearer-term robotic solar system exploration missions, such as a planned Mars rover and sample return mission, could be substantially enhanced by the capability to "top-off" upper stages in LEO.

Piloted missions to Mars will (under currently feasible scenarios) be impossible without propellant supplies at an on-orbit Cryogenic Fluid Depot. Piloted Mars mission scenarios currently under study will require on-orbit assembly of the piloted spacecraft from separately launched mission elements. The total mass of such a vehicle in LEO could exceed one million pounds - seventy-five percent (75%) of


Conceptual illustration of a cryogenic fluid depot in low Earth orbit

which would be for cryogens. (The primary cryogens for this application would be propellants, with possible additional cryogens for life support and/or instrument cooling.) In addition, this mission would require cryogen storage for over two years to fuel return-transit staging from Mars orbit.

In order to provide a "Cryogenic Fluid Depot" capability, techniques for the long-term storage of cryogens in LEO, and elsewhere, will be required. Transfer of cryogenic fluids from storage to user-spacecraft in a microgravity environment will also be required. In addition, a variety of supporting services technologies such as robotics for spacecraft manipulation during refueling will be required.

3.3.2 Technology Assessment

Three systems currently exist for managing cryogenic fluids in a space environment: 1) small-scale storage and supply systems for superfluid helium; 2) small-scale supercritical fluid supply systems for hydrogen and oxygen; and 3) large-scale vehicle cryogen propulsion systems. None of these systems currently meet critical requirements for long-term storage, supply and transfer of liquid hydrogen and liquid oxygen, nor do they meet the requirements of vehicle, tankage, and facility operations in a microgravity space environment.

Current technology programs are focused on developing a large-scale, space-based system to meet these requirements. Analytical models are under development, test facilities are being upgraded, and contracting efforts to perform in-space experiments are being planned.

3.3.2 Program Description

The goal of the Pathfinder On-Orbit Cryogenic Fluid Depot Program is to develop the technology base required to perform storage, supply, and transfer of subcritical cryogenic liquids in a microgravity space environment. The long-term goal of this technology program is to enable on-orbit fueling and/or cryogen resupply operations for future spacecraft and space transportation vehicles, and to provide the technology for very-long term storage of cryogenic fluids in space.

Program objectives include:

(1) Development of depot conceptual designs from which critical technology areas will be identified, since the criticality of a technology depends on the depot concepts

assumed;

(2) Performance of critical research and advancement of technology readiness levels in the areas of Fluid Management and potentially in the areas of Depot Operations, Structures and Materials, Orbital Operations and Logistics, and Safety. This will include large-scale ground testing and/or analytical modeling of all critical technology items considered to be enabling to the operations of a Depot; and

(3) In-Space requirements for flight testing will be defined, even though flight experiment development is not within the scope of this program.

Initial studies will be performed to identify cryogenic fluid user needs and requirements and to develop on-orbit cryogenic fluid depot concepts to meet the identified requirements. From these depot concepts, technology requirements and deficiencies will be identified. For each of the identified technology deficiencies, a technology roadmap will be prepared which defines the criticality of the identified technology, assesses the current state of technology readiness and the state of technology readiness required for the development of an operational on-orbit cryogenic fluid depot. Additionally, it will identify generic technology efforts in other program areas and assess the value of that work in providing the technology readiness levels required. These roadmaps will be used to lay out a time-phase technology program in each area.

Cryogenic fluid management technologies are inherent in all potential on-orbit cryogenic fluid depot concepts. A detailed technology roadmap and program was developed under the R&T Base Program in FY88. The program includes analytical modeling, ground-based experimentation and flight experimentation. Flight experimentation requirements are being defined and are required for technology development even though the funding requirements for the experiments exceed the current projected funding levels for the On-Orbit Cryogenic Fluid Depot element in Project Pathfinder.

Cryogenic fluid managements technologies have also been identified as the most critical area for development to enable an on-orbit cryogenic fluid depot. On the basis of that assessment, the overall Cryogenic Fluid Depot program emphasizes that area in the near term. Once mission studies, user needs and requirements and depot concepts are developed, it is conceivable that additional critical technologies may be developed.

In order to evaluate the interaction of various depot subsystems and components, a ground-based (1-g), subscale depot demonstration is required. If budget permits, this demonstration may include but not be limited to thick insulation materials, para-to-orto conversion, light weight tankage, multiple vapor-cooled shield, a thermodynamic vent system, a fluid mixer, and possibly refrigeration and/or liquefaction. A ground-based demonstration will also serve as a ground testbed for gauging and leak detection instrumentation.

The program will be implemented in two phases. The first phase will validate the fluid management ground technology and will establish depot concepts consistent with agency mission planners. The second phase will validate sub-scale depot subsystems and component interactions in a ground-based demonstration.

Deliverables

PHASE I. By the early-to-mid 1990's concept formulation for a full-scale depot will have been completed. Analytical models describing all aspects of low gravity

cryogenic fluid management (including storage, supply and transfer) will be developed and validated as much as possible with normal gravity testing. Ground-based testing of instrumentation components will be largely completed. A depot technology roadmap will be completed assessing the current state of technology readiness and the state of technology readiness required for the development of an operational On-Orbit Cryogenic Fluid Depot. This roadmap will be used to define a time-phased technology program in each area.

PHASE II. By the late 1990's, ground-based (low gravity) validation of subsystems and integrated cryogenic fluid management analytical models will be completed. The ground-based subscale depot demonstration will be in progress. (Note: If approved separately, a cryogenic fluid management experiment may be implemented by the late 1990's.)

3.3.4 Organization and Management

Work Breakdown Structure. Figure 3-3 provides the top level work breakdown structure (WBS) for the program. This structure may be revised and refined until the program is established in sufficient depth. This program is organized primarily along technology needs.

Management Structure. The overall program will be managed by a program manager in the OAST Propulsion. Power and Energy Division (RP). Technology project management responsibility will reside at LeRC in the Cryogenic Fluid Technology Office (CFTO). The program manager will have the responsibility of coordinating with other programs and Pathfinder elements to avoid duplication of efforts and to ensure that all technologies are being adequately

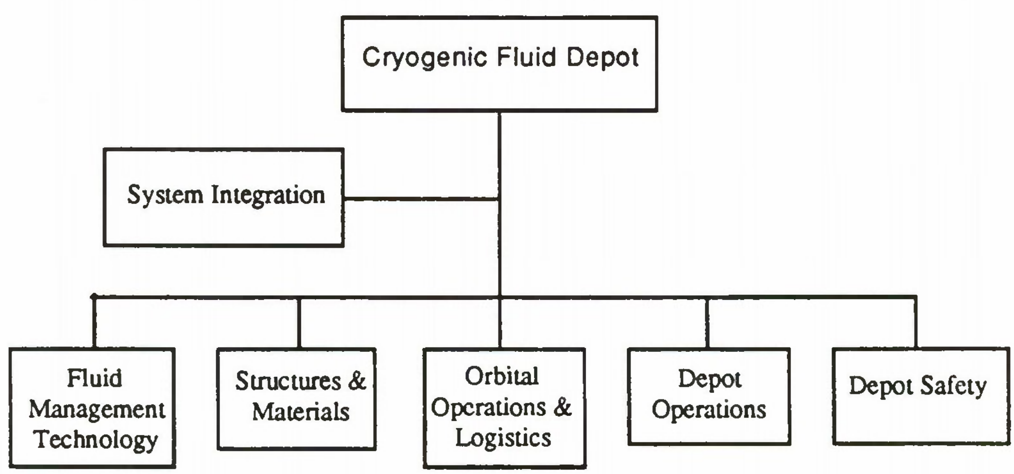


Figure 3-3
Work breakdown structure for the Pathfinder Cryogenic Fluid Depot Technology Project

addressed. The technology project manager will have the responsibility within the program of ensuring that specific technology efforts are coordinated through matrixed responsibilities in each technology discipline. The technology project manager will utilize discipline branches within the LeRC Cryogenic Fluid Technology Office as well as the expertise available the the LeRC Advanced Space Analysis Office, the Jet Propulsion Laboratory (JPL), and the Johnson Space Center (JSC) and other NASA centers as appropriate. Figure 3-3 depicts the current management structure for the On-Orbit Cryogenic Fluid Depot Program. As additional technology needs become apparent, additional NASA centers may become involved.

LeRC will have the responsibility for leading the development of a technology project plan and for the administration of the plan through the program. All participating centers will be responsible to the project manager for all questions including resources, program responsibilities, and administrative matters pertaining to reporting, scheduling and milestones.

Program Coordination. The On-Orbit Cryogenic Fluid Depot Program element of Pathfinder will be closely coordinated with appropriate personnel in the Office of Space Flight (OSF). Within OAST, coordination will be maintained with the ongoing CSTI programs in the area of automation and robotics in OAST/RC, with OAST/RM in the area of materials and structures, and with OAST/RX in the area of flight experimentation. In addition to mission analyses and requirements definition within the program, this effort will also be coordinated with the missions studies activities of the Office of Exploration (OEXP), the Office of Space Science and Applications (OSSA), the Office for Space Operations (OSO), and the Office of Space Station (OSS). As appropriate, mission enhancements through technology applications will be recommended to those offices.

A systematic approach to the technology issues of a space-based fluid depot will begin with the definition of the system requirements. These requirements will be generated by considering the missions which will require depot support. These requirements will be collected from the user organizations (Codes C, E, M, S, and Z) and catalogued in a database. Depot conceptual designs that satisfy these requirements will be generated; from these, critical technology areas will be identified. Coordination in these efforts will ensure consistency of these depot concepts with current agency planning.

Resources. Projected resources to meet the goals and objectives of the Cryogenic Fluid Depot Technology Program for fiscal years 1989 through 1993 are approximately $25 million. The resource allocation for the project for FY 1989 will be $3 million.

Section 3.4
Space Nuclear Power

3.4.1 Technology Requirements

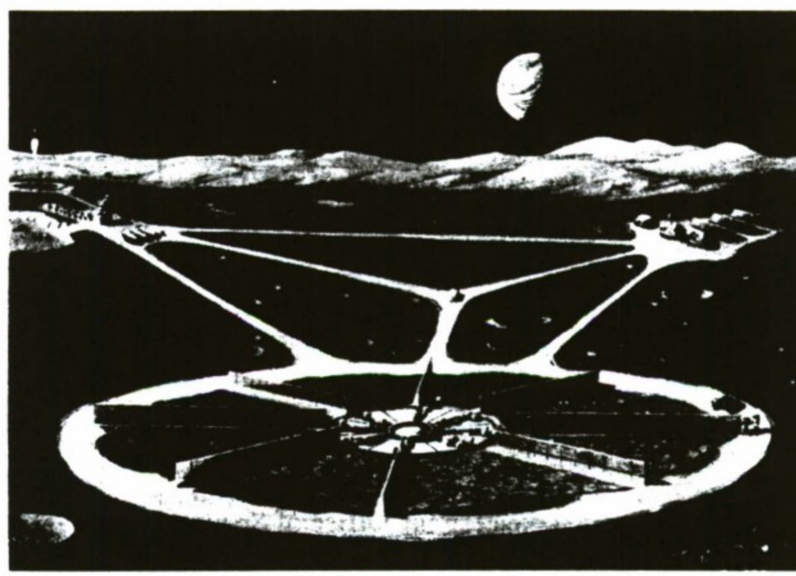
NASA planning for future solar system exploration includes a variety of missions which could either be enabled or substantially enhanced by the availability of high-levels of electrical power. These include both piloted and robotic solar system exploration missions, such as outer planet spacecraft and planetary surface applications. The continuing or periodic unavailability of solar radiation, or the requirements for very high power levels, make photovoltaic or solar dynamic power systems in combination with chemical power storage technologies infeasible as the long-term

primary power source for the mission. Space nuclear power can meet the power requirements of these missions.

An initial outpost on the Moon (or Mars) will require approximately one hundred kilowatts (100 kW) of continuous electrical power for operations; these include life support, science, in situ resource processing research, and general outpost installation power needs. As these initial outposts evolve toward permanently inhabited bases, their power requirements will grow to the megawatt range, supporting surface mining, in situ oxygen production (for propellant and life support utilization), closed-loop life support systems, and substantially augmented science operations. Space nuclear power systems - applied to a Lunar outpost, for example - can result in low Earth orbit (LEO) mass savings of hundreds of tons. For a permanently inhabited Lunar outpost, the savings can be on the order of thousands of tons in LEO.

Similarly, a piloted "sprint" mission to Mars could benefit substantially from the application of space nuclear power. Utilized as the high power source for electric propulsion of a cargo vehicle for a mission, space nuclear power can result in a mass savings in LEO equivalent to approximately three-to-five heavy lift launch vehicles (HLLVs) - compared to a comparable cargo vehicle utilizing chemical propulsion and aerocapture at Mars. Similar savings in LEO mass requirements and in reduced time spent in transit would result from the successful application of space nuclear power to electric propulsion for robotic missions to the outer planets.

Future power requirements growth may also be needed to support non-planetary missions. These might include support for low Earth orbit (LEO) activities such as materials processing and in-space manufacturing, civil air and ocean traffic control systems. (The latter might operate in the high radiation belts.) These missions would benefit substantially from the availability of reliable, long-life space nuclear power systems.



Conceptual illustration of a space nuclear power system providing power to an advanced Lunar outpost

3.4.2 Technology Assessment

The SP-100 Program is the only space reactor development program in the United States today. A much earlier effort, the SNAP-10A system, represented this country's first and only pre-SP-100 space nuclear reactor system. The SNAP-10A provided about six hundred watts (600 W) of electrical power, with a system efficiency of about one and one-half percent (1-1/2 %)

in April, 1965. The thermal reactor operating temperature was of the order of 980°K with a system design life of one year. SNAP-10A technology is inadequate, both lifetime and power level, to support projected long-duration Lunar surface operations or other solar system exploration missions.

Terrestrially, liquid metal reactors have been operated at 600 to 750°K. Current power conversion technology, represented by thermoelectric static conversion using silicon-germanium materials, provides approximately four and one-half percent (4 1/2 %) conversion efficiency for the temperature gradient of interest.

3.4.3 **Program Description**

The Pathfinder "Space Nuclear Power (SP-100)" Program represents NASA's participation in the on-going "SP-100 Ground Engineering System (GES) Project" being managed by the Department of Energy (DoE).[2] The objective of the SP-100 effort is to develop and validate the technology for space nuclear reactor power systems that can produce 10's to 100's of kilowatts of electric power and be capable of seven years of operational life at full power.

The GES Project's objectives will be accomplished through selected components' technology development and by validating the performance of the system through a Nuclear Assembly Test (NAT), and an Integrated Assembly Test (IAT).

The objective of the NAT is to test a full-scale reactor, as well as the instrumentation and control for the operation of the reactor, and the radiation shield in a simulated space environment. The objective of the IAT is to test a modular segment of the power conversion and radiator subsystem with an electrically heated reactor simulator.

Lifetime and long-term performance of the system will be modeled, and validated through extensive component testing.

The SP-100 GES effort needs to advance space nuclear power system technology in several key areas. These include high temperature (1350°K) refractory alloys, high temperature control devices for reactor operations, thermoelectric electromagnetic pumps, high efficiency thermoelectric converters, light-weight heat pipe radiators, and power conditioning and control. Safety assessment and design and/or operational considerations are a major aspect of the GES program. The safe operation of the reactor must be assured for both normal and off-normal situations, on the ground, at launch, during operations, and during post-operations/end-of-life disposal.

In the SP-100 Program, space nuclear power technology developments are being conducted in three phases.

Deliverables

PHASE I. The "Phase I" SP-100 program was initiated in 1983 with a survey of potential civilian and military applications of space nuclear power. Based on projected applications, system requirements for the GES were defined and multiple contracts were let to assess several concepts and technologies that could meet those systems requirements. Phase I was completed in September, 1985. A reactor and conversion systems were selected, and a power level was recommended.

PHASE II. In 1985, "Phase II" proceeded with the decision to implement the GES

2. *Note: The SP-100 GES Project is a joint effort between the Department of Energy (DoE), the Department of Defense (DoD), and NASA.

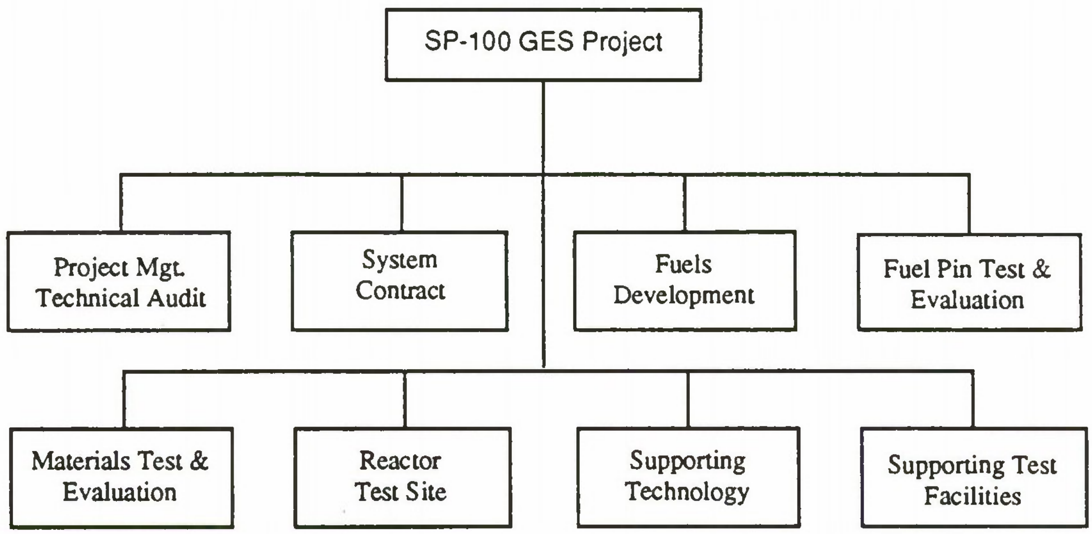


Figure 3-4
Work breakdown structure for the SP-100 Ground Engineering System Project

Project. In this phase, a reference flight system is being designed at the one hundred kilowatt (100 kWe) electrical power level, and the requirements of the GES on subsystems and components are to be defined. System performance is to be demonstrated separately through a Nuclear Assembly Test (NAT) and an Integrated Assembly Test (IAT).

System lifetime will be demonstrated through component-level testing; life models will be developed. System reliability, survivability, scalability, and safety will be demonstrated through testing and analysis at the system level. A reference flight system design for Phase II has been defined.

Following Phase II, a flight demonstration (Phase III) of an SP-100 system is being considered. Planning is currently underway for this phase.

3.4.4 Organization and Management

The SP-100 Space Nuclear Power Program is an on-going DoE/DoD/NASA effort and is under the cognizance of an Interagency Steering Committee established by a memorandum of agreement (MOA) between DoD, DoE, and NASA. NASA's contribution is transferred in a single block to DoE for sponsorship of the effort.

Work Breakdown Structure. Figure 3-4 provides a preliminary work breakdown structure (WBS) for the program. The program is organized along discipline lines, with a systems contractor who has responsibility for integration of all activities. JPL is responsible for overall GES project management with General Electric (GE) serving as system contractor. LANL has project management responsibilities for nuclear systems.

An ICB is formed for each activity outside the system contract with members from GE, the project office, and the individuals responsible for the activity. The function of the ICB is to ensure that the various activities are in phase with overall project flow and consistent with the tasks of the system contractor.

Management Structure. Overall program coordination will be directed by a Program Manager in RP. Management of the SP-100 GES Project is through the organization established by DoE.[3]

Program Coordination. The SP-100 GES Project involves three government agencies: DoE, DoD, and NASA. The SP-100 GES Project involves four DoE laboratories: Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Hanford Engineering Development Laboratory (HEDL), and also involves two NASA field centers: the Jet Propulsion Laboratory (JPL) and the Lewis Research Center (LeRC).

Within OAST, the Space Nuclear Power Program is coordinated with the on-going Civil Space Technology Initiative (CSTI) High Capacity Power Program. Opportunities for performance growth, reduced mass, and increased reliability and lifetimes are the key areas for consideration.

Resources. The resources allocated for the SP-100 GES technology development project are provided from the three partners in the effort, DoD, DoE, and NASA. At present, the NASA/Pathfinder share of those resources for the fiscal years 1989 through 1993 are projected at $ 105 million. The FY 1989 allocation is $10 million.

3. See the SP-00 GES Project Management Plan for additional information.

Section 3.5
Resource Processing Pilot Plant

3.5.1 Technology Requirements

The use of non-terrestrial resources has the potential to provide substantial benefits to a wide variety of future activities in space by dramatically reducing the amount of material that must be launched from Earth, and resultant high transportation costs. For example, Lunar rocks and soil could be processed into life support supplies, propellants, construction materials and shielding for general use in space, as well as on the Lunar surface. This could include resupply of low-Earth orbit (LEO) stations, and outfitting interplanetary missions originating from the Moon. Furthermore, any process developed for the Moon would provide the knowledge and experience required to develop similar processes in space or on other planets in a low gravity environment (such as oxygen and propellant production on Mars).

The first step in establishing the capability to produce needed materials from extra-terrestrial resources will be the validation of materials handling and processing technology during a period of Earth-dependent exploration. This will lead to increasing self-sufficiency for an array of space activities. This will be accomplished through small pilot plants. Currently, sufficient technology does not exist to select the raw materials or processes, or to design pilot plants for this purpose.

3.5.2 Technology Assessment

There is currently no established program to develop the technology to process extra-terrestrial materials. While many potential processes have been identified for the

processing of Lunar and Martian materials, few have been explored in the laboratory. The feasibility of producing fiberglass and bricks from Lunar soil has been demonstrated by heating and compaction processes. To date, efforts have concentrated on the feasibility of producing oxygen and metal (iron) from Lunar soils. Currently, one company is looking at Lunar oxygen production by fluidized bed hydrogen reduction of ilmenite (an oxide of iron and titanium), and another is looking at electrochemical liberation of oxygen from Lunar simulant anorthite (a silicate of calcium and aluminum).

In the hydrogen reduction process, ilmenite is converted to oxygen, and titanium dioxide. A key consideration for this process is that the hydrogen required to reduce the ilmenite is recoverable. This fact is critical because hydrogen is very scarce on the Moon (approximately 75 ppm) while regolith is about 46% oxygen. While these processes, and a few others, are being evaluated on a laboratory scale, there are many other potential chemical processes that need to be evaluated for feasibility. In addition, there has been no significant effort on the collection and sorting of Lunar soil and rocks, or on the automation of potential processes for utilizing Lunar resources.

3.5.3 Program Description

This element of Pathfinder will focus on developing the processing technology for the collection, extraction, and production of useful materials from extra-terrestrial resources. The initial emphasis will be on the production of oxygen, metals, and construction materials on the Moon. This effort will serve as the basis for a broader program to develop processing/production/manufacturing technology for a permanent, and self-sufficient Lunar settlement and for other planetary outposts. Lunar rocks and soils contain significant amounts of oxygen, metals (iron, titanium, aluminum, magnesium, silicon), and glasses which can be processed for utilization as life support supplies, propellants, construction materials, and shielding materials.

In order to capitalize on the potentials of these Lunar resources, the technology for the Lunar operations necessary to collect and sort materials on the Moon, as well as the extraction and processing methods themselves must be developed. The Resource Processing Pilot Plant program will provide the basis for the development of large-scale autonomous processes for the utilization of Lunar resources to support permanent Lunar bases.

In the near-term, the Resource Processing Pilot Plant program will focus on developing chemical/physical processes for producing oxygen, metals and construction materials on the Lunar surface. Consideration will be given to other extra-terrestrial environments but, as a minimum, the program will be planned to meet requirements of a Lunar outpost. Within that context, the highest priority will be given to oxygen production for life support.

At the beginning of the program, several methods will be supported - leading to selection of the most promising for further development. Process evaluation criteria will include raw material requirements, power consumption, process durability (life time of production hardware), compatibility with automation and overall synergism with other processes to reduce complexity. To guide the selection process, overall pilot plant systems studies will commence at the beginning of the program. Also, to support process development, Lunar simulants will be reproduced and methods of material collection and handling will be studies. (To the extent possible collection and handling methods development may also be conducted, but at lower priority than process development.)

Processes to collect and sort materials robotically will also be identified and developed, but at lower priority than process development. However, it is important to consider these issues early in the program to guide the selection of candidate production processes.

Selected processes will then be developed individually in the laboratory, but with a stronger emphasis on technology development than fundamental process development. This will lead to the selection of a final set of methods (possibly more than one for each product) to be developed in an integrated manner. At the same time, a conceptual design for a pilot plant (or plants) will be developed. The plant concept and integrated methods development will emphasize validation of the ability to produce needed materials efficiently, reliably and in large-scale through a small pilot plant. Eventually, a laboratory pilot plant will be built to optimize and validate integrated production methodologies and hardware concepts.

Deliverables

PHASE I. By the early-to-mid 1990's the processes to extract oxygen, metals, and other useful materials economically from Lunar soil will be demonstrated on a laboratory scale and the candidate processes for Lunar pilot plants will be identified. Some telerobotic concepts for collection, handling, and sorting Lunar materials will be developed. Lunar processing methodologies will be developed that have low power requirements, minimal dependence on Earth-supplied and scare Lunar materials, and overall synergistic relationship among themselves to reduce complexity. The processes developed must also be durable.

PHASE II. By the late 1990's benchtop pilot plants compatible with autonomous operation which require only a minimal degree of monitoring will be developed for the utilization of the abundant Lunar resources. They will be validated by simulating Lunar operations on artificially produced Lunar materials. Technology will be in place to begin development of actual hardware systems for a Lunar mission. Also, process scalability will have been demonstrated to satisfy the eventual requirements to have a plant on the Moon with the capability of processing large quantities of resources.

3.5.4 Organization and Management

Work Breakdown Structure. Figure 3-6 provides a preliminary work breakdown structure (WBS) for the program. The WBS will consist of four main elements. The first is basic methods development. All individual methods evaluation and development will be conducted under this element. A second element will address raw materials preparation. This will include the production of Lunar simulants of raw materials to support process development and robotic collection. Also, any methods for physical or mechanical preprocessing or separating of materials would be conducted under this element (e.g. crushing, electromagnetic separation).

The third element of the work breakdown structure will focus on process engineering. This will include mechanical systems, instrumentation, gas separation, and thermal management. Concepts for process automation and control will also be considered in this work package. Technology developed from these activities will enable the design of efficient, durable production pro-

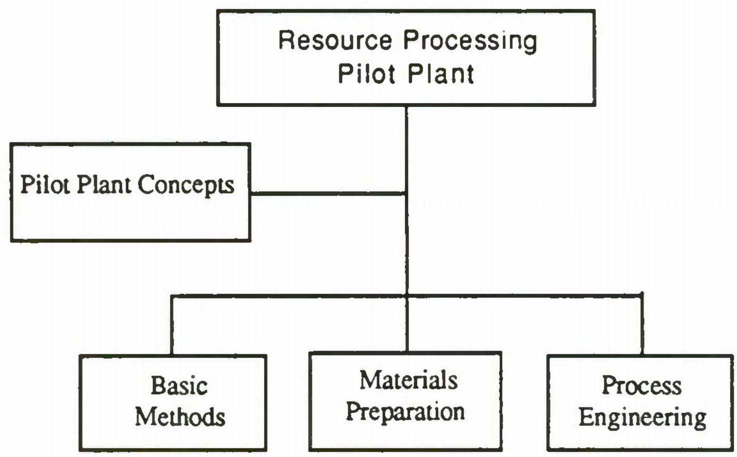


Figure 3-5
Work breakdown structure for the Pathfinder Resource Processing Pilot Plant Technology Project

cesses at a representative pilot plant.

The fourth element will focus on pilot plant concepts including conceptual design (and later in the program construction of a laboratory pilot plant). This element will also address synergism with other extra-terrestrial resources (such as Martian) and develop a long range program building from the technology for a Lunar pilot plant. As such, should NASA mission priorities for resource processing shift away from the Moon, the Resource Processing Pilot Plant element of Pathfinder will be in a position to focus on these requirements.

Management Structure. The overall program will be managed by a program manager in the OAST Materials and Structures Division (RM). During the initial planning phase a technical advisory committee will be formed consisting of selected technical specialists from field centers, RM, the OAST Space Directorate (RS), and representatives from OSSA and OEXP. The committee will be chaired by RM and remain in place for the duration of the program, with membership adjusted as required. This committee will be charged with evaluating the technical goals, objectives and progress of the program as related to an established program plan. After a program plan has been developed and approved within NASA, membership may be expanded outside of NASA.

The lead center for development of a detailed program plan is the NASA Johnson Space Center (JSC). This center will have responsibility for leading the development of a program planned for administration of the plan throughout the program. A program coordinator will be assigned at JSC for that purpose. The key participating center identified at this time for program development and implementation is the Jet

Propulsion Laboratory (JPL). All eventual participating centers will be responsible to the program manager in RM for all areas involving resources and program responsibility. They will be responsible to the lead center in administrative matters pertaining to reporting, schedule and milestones.

Program Coordination. The Resources Processing Pilot Plant element of Pathfinder will be closely coordinated with the Office of Space Science and Applications (OSSA) and the Office of Exploration (OEXP). Within OAST, coordination will be maintained with the Information Sciences and Human Factors Division (RC) in the areas of automation and robotics and with the Space Directorate (RS) as the focal point for all Pathfinder elements.

Resources. Resource requirements for the fiscal years 1989 through 1993 are projected at approximately $21 million.

Section 3.6
Optical Communications

3.6.1 Technology Requirements

NASA planning for future solar system exploration includes piloted and robotic missions to the Moon, Mars, and the outer planets. The success of future solar system exploration missions will depend upon a wide variety of factors. A key measure of mission success is scientific productivity. Maximizing scientific productivity for a given spacecraft can be accomplished by providing high data rate communications between the spacecraft and mission operations on Earth (or the Space Station).

Radio frequency microwave communications technology requires, for a fixed gain, either higher frequencies or larger antennas. Current radio frequency (RF) antennas are beginning to dominate the overall structure of typical robotic spacecraft. Ambitious robotic and piloted missions not only require higher data rate performance, they also impose stricter constraints on available power, mass, and volume, for all spacecraft subsystems - including communications. In long-term surface applications, ruggedness and reliability will be important requirements. Even without constraints, RF technology would be hard-pressed to provide the orders of magnitude increases in data rates required to maximize scientific productivity for the broad array of potential future missions of solar system exploration.

Optical communications technologies could reduce the size of transmitter/receiver antennas by over a factor of ten (10:1 reduction), while offering multi-gigabit per second data rates in Earth orbit, multi-megabit per second data rates throughout the inner solar system, and multi-hundreds of kilobits per second performance to the outer planets.

Unique NASA technology requirements for communications systems include high data rates, very high sensitivity receivers, large multimeter receiver apertures, and/or very long distances communications. Moreover, NASA can utilize the latent potential in the transmitted beam to do science as well as communications. The science requirements could be accommodated by having a laser and telescope on the spacecraft. Experiments such as laser scattering off ring particles, laser induced absorption and emission properties of planetary atmospheres, and selected backscatter lidar should be possible.

NASA also uses a spacecraft's communications beam for deep space navigation. Optical communications can meet this technology requirement. Borrowing from

techniques developed by the astronomy community, astrometric navigational tracking of a spacecraft from a single optical telescope should yield navigation precision two orders of magnitude better than current intercontinentally-spaced microwave very long baseline interferometry (VLBI) tracking. Other studies indicate that optical heterodyne communications will enable missions such as Starprobe which require realtime communications while the spacecraft travels through the Sun's plasma.

3.6.2 Technology Assessment

At the present time, spacecraft communications are accomplished at microwave frequencies, primarily at X-, Ku-, or Ka- band. At these frequencies, the spacecraft system is dominated by the antenna, which can be up to four-to-five meters in diameter. At the same time, the Deep Space Network (DSN) - the receiving stations for deep space spacecraft communications - includes the world's largest steerable radio telescope arrays. Despite the tremendous DSN arrays and large spacecraft antenna sizes, however, data rates using RF frequencies can be the limiting factor in the scientific return of a mission. In the case of the Voyager mission, the maximum data rate possible was a meager twenty-two kilobits per second (22 kbps) at Saturn encounter.

Microwave communications will severely impact potential scientific return from present missions and seriously compromise even minimal future ambitious solar system exploration mission data requirements. Studies indicate that optical communications systems will communicate from deep space and near-Earth distances with data rates in the tens-to-hundreds of megabits per second(10s-to-100s of mbps) to the tens of gigabits per second (10s of gbps).

Important technologies which must be developed and/or improved include diffraction-limited laser transmitters with high powers and long lifetimes and pointing systems capable of sub-microradian accuracies. All of these technologies must be developed and demonstrated in space to validate readiness for operational use.

An advanced robotic probe transmits high-rate scintfic data back to Earth from Saturn

3.6.3 Program Description

The goal of the Pathfinder Optical Communications Program is to carry optical communications technology to the level of readiness required for future selection of this technology for flight system applications in low Earth orbit (LEO),

geostationary Earth orbit (GEO), and beyond. To accomplish this goal, Pathfinder Optical Communications Program will develop the flight-qualified component and system technologies required to flight demonstrate the transfer of data at mega- to giga- bits per second rates: (1) from GEO to LEO, (2) from GEO to GEO, and (3) from deep space to Earth and/or LEO.

Critical technology objectives include the development of lightweight highly efficient laser transmitters, high precision pointing and tracking systems, large aperture lightweight receiver telescopes, and high sensitivity direct and heterodyne detection systems.

The components will be incorporated in an engineering system and first tested in a LEO (GEO to LEO or LEO to LEO) technology demonstration. Next, optical pointing, tracking, and communication performance will be demonstrated in a spaceborne mission by returning data at a twenty megabit per second (20 Mbps) rate from Mars to either GEO, LEO, or Earth. The latter objective may be accomplished by means of a flight experiment package on-board the Cassini mission. The data obtained from these Pathfinder technology demonstrations are prerequisite for the demonstration and selection of operational deep space and near-Earth optical communications systems.

Mission analysis and requirements studies will be performed to guide technology development and the definition of planned Earth orbiting and deep space technology flight demonstrations of optical communications. In addition, research and development of selected components will be initiated and concentrated in the areas with the highest system benefits. Operational limits of optical communications systems will be explored and expected performance will be validated.

The Pathfinder Optical Communications Program will focus on the Laser Technology Experiment Facility (LTEF) which is Space Shuttle-based, and a Cassini spacecraft-carried flight experiment package.

The program will build on technology component development performed as part of the OAST Research and Technology Base program. Component research development will concentrate on the most challenging and high-potential discipline areas in spaceborne optical communication systems; these include:

(1) laser transmitters (semiconductor diode arrays or diode array-pumped solid state lasers with possible injection locking) with high power, high reliability, and medium-to-high modulation rates,

(2) sub-microradian accuracy open- and closed- loop pointing and tracking systems,

(3) direct and heterodyne detection components for receivers, and

(4) associated optical components such as mirrors, lenses, and filters.

A breadboard ground technology demonstration of the components in a simulated space environment will be done. Then two engineering flight demonstrations are possible during the mid-to-late 1990's. The first experiment could involve a laser communications link between the Pathfinder-developed LTEF and either a GEO or LEO optical communications terminal.. The later flight experiment can demonstrate deep space capabilities using a Pathfinder-developed optical communications package on board the Cassini spacecraft and either an orbital or an Earth-based receiving terminal.

3.6.4 Organization and Management

Work Breakdown Structure. The work breakdown structure for this program is still being defined. The program will be organized along discipline lines. Mission planning and flight experiments will provide near-term results and a near-term focus to the program.

Management Structure. The Optical Communications Program will be managed by a Program Manager in the OAST Information Sciences and Human Factors Division (RC). An Optical Communications Working Group (OCWG), chaired by the Code RC Program Manager, will help formulate program plans and facilitate management communications. A lead center will be identified for the program, with responsibility for technical integration and reporting. Responsibility for center assignments and allocation of funds will remain with the OAST Program Manager. The OCWG will provide intramural and extramural coordination between NASA Centers and the federal industrial and university communities.

Program Coordination. The Optical Communications Program will be coordinated with the following NASA program offices: (1) the Communications and Data Systems Division (EC) and the Planetary Exploration Division (EL) of OSSA, (2) The Office of Space Operations (OSO, NASA Code T - which is assessing the feasibility of optical systems for NASA's operational use), (3) the Office of Exploration (OEXP - as responsible for piloted exploration mission studies), and (4) the Office of Space Station (OSS - as a possible carrier for the Cassini flight demonstration receiver station). Recommendations from these offices will be considered when studying or planning specific experiments and technology activities.

Resources. The Optical Communications Technology Project's anticipated resource requirements for fiscal years 1989 through 1993 are approximately $25 million.

Chapter 4
Humans-In-Space

The objective of the Humans-In-Space program area is to conduct research to define requirements, and to develop, technologies that will enable or significantly enhance future piloted Solar System exploration. The principal focus is on two mission goals: the exploration of Mars, and the beginning of extended human operations on the Moon.

From its earliest days, research and technology to allow safe and effective human operations in space have been at the forefront of issues confronting the U.S. civil space program. Basic human health in space started out as a great unknown. Life support systems and "spacesuits" for extravehicular activity (EVA) were two critical challenges that faced the Mercury, Gemini, and Apollo programs. The interfaces between the astronaut and the spacecraft were also problems, but because of the relatively short duration of the missions, the long-term effects of space and of confinement were not impassable barriers.

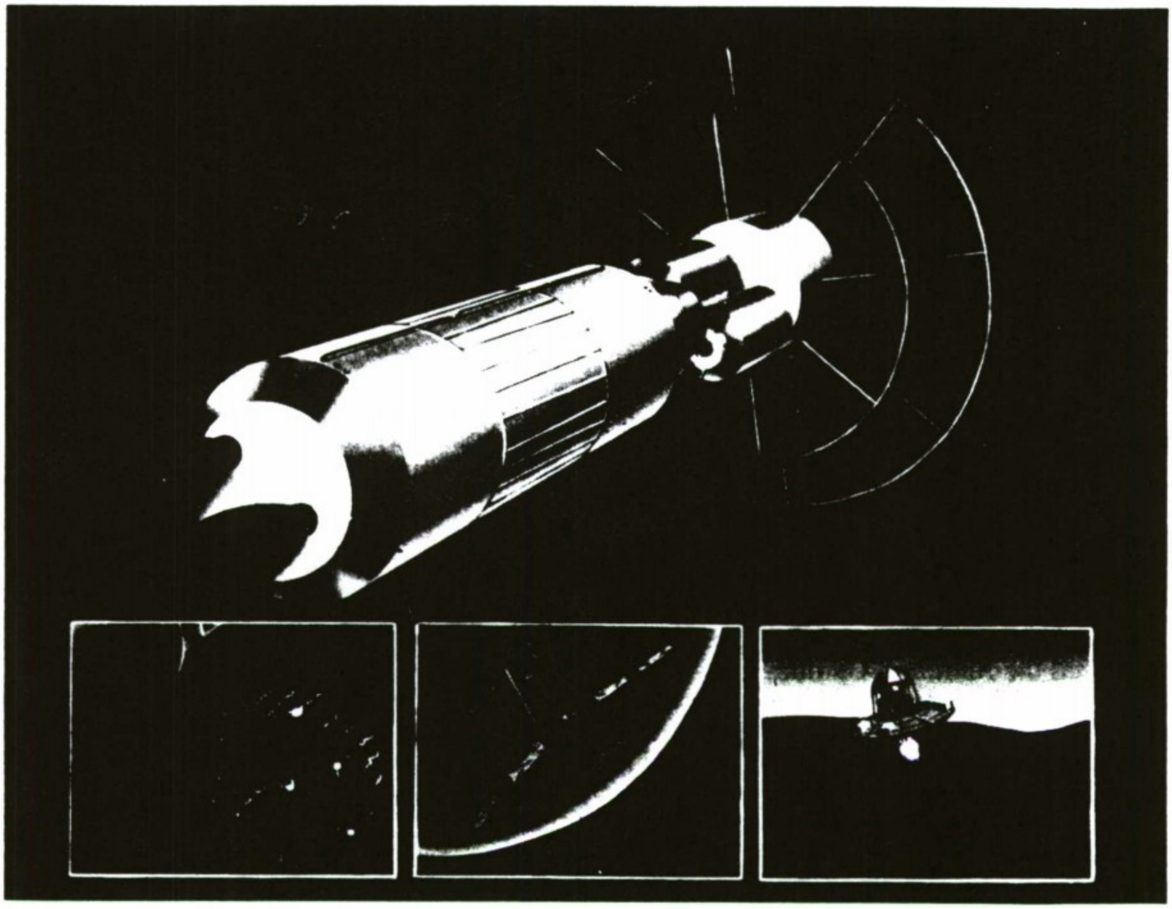
During the early 1970's, the Skylab Program provided our first - and so far our only - opportunity to study longer-term issues. Also, the development of the Space Shuttle and its systems permitted significant improvements in EVA suits, life support, and crew systems; however, as was the case with the programs of the sixties, the sortie-class missions conducted by the Shuttle to not require a resolution of longer-duration mission issues.

The Space Station will create another substantial advancement of our capabilities to support humans in space, including factors related to longer-duration human flight. However, although forming a foundation upon which to build, the operational systems of the Station will not provide us with the capabilities we need for future, very long-duration missions to the Moon or Mars.

Pathfinder Humans-In-Space efforts consist of a family of closely-coordinated technology projects. These are organized in three element-areas: (1) Extravehicular Activity (EVA)/Suit (including both requirements definition and technology), (2) Human Performance (including space human factors, microgravity countermeasures, radiation effects and countermeasures), and (3) Closed-Loop Life Support Systems (including both physical-chemical systems and bioregenerative systems).

Detailed FY 1989 planning for these elements is still being finalized. Discussions of these plans will provided in the final version of this Program Overview.

Pathfinder



Chapter 5
Space Transfer

The objective of the Space Transfer program area is to develop advanced space transfer capabilities that will enable or significantly enhance future piloted solar system exploration. The principal focus is on two functional capabilities: space propulsion and aerobraking.

The capability to move effectively from one orbit to another in space is a fundamental requirement for space operations. A variety of "space transfer" propulsion systems have served the needs of the civil space program since the 1960's - ranging in complexity from simple expendable upper stages, to the all-purpose service modules of the Apollo missions. Consistently, technology development programs in propulsion have sought improvements in engine performance (specific impulse and thrust) and advances in engine reliability. To those long-standing goals, the advent of planning for the Space Shuttle and the Space Station have added the objectives of reusability and space maintainability to the traditional list, as well as the goal of permanent space-basing of space transfer systems..

Use of a planetary atmosphere to slow the speed and change the trajectory of spacecraft is another art that dates back to the 1960's. NASA's first efforts were the low life-to-drag (L/D) ratio Mercury, Gemini, and Apollo capsules; these used ablative heat shields to protect the mission's crews from the extreme heat of reentry.

Developed from those earlier technological foundations, the Space Shuttle represented a major advance in "aeroassisted" maneuvering. The Shuttle's winged-shape provides an extensive cross-range maneuvering capability during reentry, and its thermal protection tiles approach to the heating problem allows comparatively rapid operational

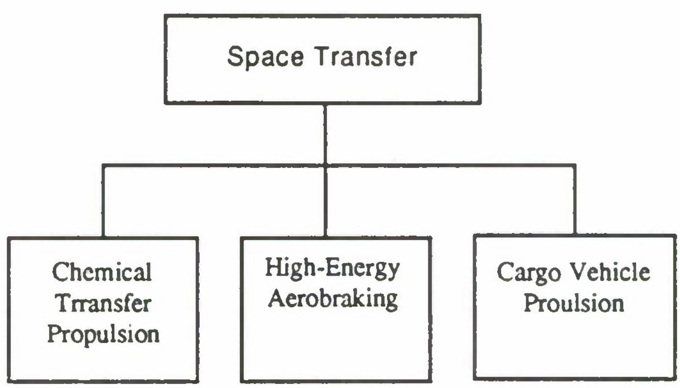


Figure 5
Work breakdown structure for the Pathfinder Space Transfer Program Area

turn-around of the vehicle. At the same time, NASA was also applying Apollo-style aero-ballistic entry techniques and ablative heat shields to the problem of entry and landing at Mars for the robotic Viking spacecraft in the late 1970's. Various studies have explored the possible sue of these techniques to slow a spacecraft and modify its trajectory elegantly - without the use of propellant.

Pathfinder Space Transfer Efforts efforts consist of three technology projects. Two of those are in the area of advanced propulsion, and one is in the use of a planet's atmosphere in place of propellant; these are: (1) Chemical Transfer Propulsion, (2) High-Energy Aerobraking, and (3) Cargo Vehicle Propulsion.

Each of these is described in some detail in the subsections which follow.

Section 5.1
Chemical Transfer Propulsion

5.1.1 Technology Requirements

NASA's planning for future exploration of the solar system includes both robotic (precursor) and piloted missions to Mars, as well as a resumption of piloted missions to the Moon. One of the keys to reducing the cost of these missions is to minimize the propellant mass in low-earth-orbit required to achieve a transfer trajectory, to accomplish orbit insertion, to effect a landing on the surface, and to return to earth. This propellant mass must be delivered to low-earth-orbit by earth-to-orbit launch systems and the less propellant required in orbit to meet mission requirements means fewer earth-to-orbit (ETO) vehicle launches.

A key enabling technology that will greatly reduce in-orbit propellant mass requirements is the development and use of high performance chemical propulsion systems for the transfer, orbit insertion, lander, and earth return vehicles. Another key to reduced cost is to develop and utilize reusable transfer stages that are based in and operated from low-earth-orbit. Technologies that will enable automated in-orbit operations, including refueling, maintenance, servicing and preflight systems checkout, as well as fault tolerant in-flight operations, are critical to the successful development and use of space-based vehicle systems.

In the case of the manned Mars mission, an increase of 35 seconds of engine specific impulse (Isp) saves the cost of at least two earth-to-orbit vehicle launches assuming the transfer stage is expended. In addition, the propulsion systems developed for the Mars and lunar missions will also be applicable to a LEO-to-GEO and return orbital transfer vehicles and to transfer stages needed for the precursor unmanned missions to Mars. For lander vehicles, deep throttling by the lander engine is required for both hovering and landing. High engine performance over a wide throttle range will result in a significant savings in propellant mass required to effect a successful safe landing.

5.1.2 Technology Assessment

The only U.S. upper stage LOX/ Hydrogen engine currently in operation is the highly successful RL10 expander cycle engine which was developed and certified in the late 1950's and early 1960's. However, it is a low pressure engine that delivers moderate performance, has limited throttling capability and no on-board diagnostics. It was designed for and has been used only on expendable vehicles.

Conceptual illustration of an automated chemical transfer vehicle entering Lunar orbit

5.1.3 Program Description

The Pathfinder Chemical Transfer Propulsion Program is geared to establish the technology base that will enable the development of space-basable, high performance chemical transfer propulsion systems, as well as lander propulsion systems that can provide the needed high performance over a wide throttle range. A LOX/ Hydrogen expander cycle engine has been identified as the primary candidate propulsion system that will meet these stringent mission requirements.

Critical technologies will be developed in the areas of high performance variable flow components, high expansion ratio nozzle flow characterization, design for in-space maintainability, and integrated health monitoring/ control systems that will provide automated preflight operations, as well as fault tolerant engine flight operations. The objective of the program is to validate high performance expander cycle engine concepts, including high pressure cycle balance demonstrations, component interaction predictions, engine controls (including deep throttling), and system level health monitoring diagnostic capabilities for space-basing.

The Chemical Transfer Propulsion program will use a building block approach ranging from fundamental technologies through component, subsystem and system technology hardware demonstrations. Work in the R&T Base over the past few years has been directed towards establishing engine design concepts capable of meeting expected mission requirements and pursuing critical technology advances necessary for those engine concepts to achieve performance, life, and operational goals. Advanced design concepts and analytical methods have been developed using laboratory and especially designed test equipment to generate the data base needed for design verification and code validation.

The Chemical Transfer Propulsion program will build on the R&T Base results by moving progressively through full scale component, subsystem, and system level validation and demonstration programs. Key milestones include 1.) documented validation of full scale component hardware designs and analytical methods, including turbomachinery, thrust chamber assemblies, valves and controls, and integrated diagnostic sensors; 2.) the development and demonstration of engine performance and dynamics models utilizing an integrated component breadboard engine assembly for cycle and concept validation testing; and 3.)

the demonstration of fault tolerant engine operations, component life, and automated preflight operations utilizing advanced component designs that will be developed to meet Mars and Lunar mission requirements and then incorporated into the breadboard engine. When the technology program is complete, the operational hardware will then be available to support further engine development as an off-line testbed for problem solving and for product improvement.

The technical program will be supported by engine system level design and analysis efforts in order to compare the impact of technology advances on the assumptions originally made in the earlier concept definition studies. In addition, mission study activities being conducted by the Office of Exploration (OEXP) will be used to identify mission dependent propulsion requirements.

Deliverables

PHASE I. The first phase of this focused program will be directed toward component and subsystem level advanced design and analysis development and verification. Advanced design concepts and analytical methods that have been previously developed in the R&T Base Program utilizing laboratory, bench, and rig testing will be used in the design and fabrication of component and subsystem hardware. This highly instrumented hardware will be operated over a wide range of conditions for design verification and refinement. The output of this phase of the program will be computational codes capable of predicting component and subsystem performance, life, dynamics, and operating characteristics, as well as a broad experimental data base. This effort will also support the potential initiation in FY 1990 of an advanced development program funded by the Office of Space Flight (OSF) for the purpose of demonstrating a near prototype engine that could be developed for an early Space Transfer Vehicle (STV) designed to meet the requirements of planned high energy solar system science exploration missions. The design of that engine would be based on the component and subsystem technology being developed in the OAST program.

A parallel effort in Phase I, will be directed toward developing design methodology for advanced components incorporating the necessary features, design characteristics, and diagnostics that will lead to the definition and demonstration of highly reliable, space-basable, high-performance, throttleable engines capable of meeting future Mars/Lunar transfer, lander, ascent, and Earth return vehicle requirements.

PHASE II. The demonstrated components and subsystems from Phase I will be assembled into an early breadboard engine configuration in order to conduct component interaction and system level verification testing and to establish a system level experimental data base. High pressure expander cycle operation will be validated, and engine models for predicting transient, steady state, and throttling performance will be tested, refined and verified. The fabrication and verification testing of advanced components designed on the basis of the parallel Phase I focused technology program will also be completed during this phase.

PHASE III. The third phase of the program will follow with the overall objective of demonstrating the performance,life and transient/steady state operation of a breadboard engine system incorporating the advanced components from Phase II. The engine will have all of the design, performance and operational characteristics needed to meet the requirements of space-based transfer, lander, ascent, and Earth return vehicles, including automated preflight operations, in-space maintainabili-

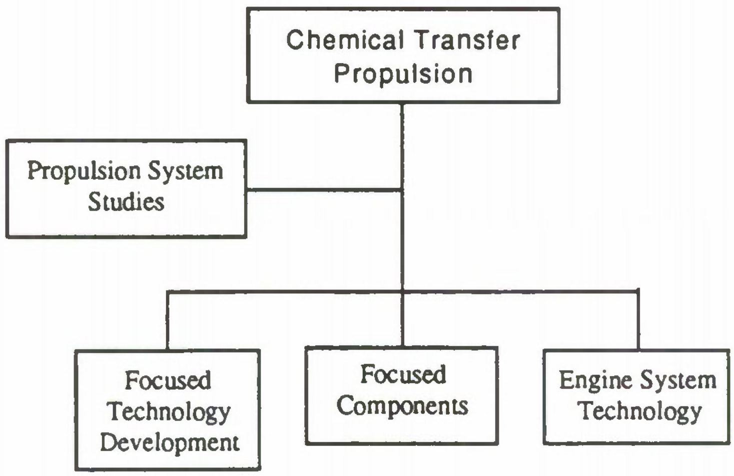


Figure 5-1
Work breakdown structure for the Pathfinder Chemical Transfer Propulsion Technology Project

ty, and fault-tolerant flight operations. When this phase of the program is complete, the hardware will be available for use in further engine development as a testbed for problem solving and for product improvement activities. The projected completion date is FY 1997.

5.1.4 Organization and Management

Work Breakdown Structure. The program is organized as shown in Figure 5-1. The work breakdown structure allows work to be focused in several critical areas and also provides a flow mechanism for raising the technology to higher and higher hardware definition levels, while focusing the technology results into engine system level analysis studies in order to assess progress towards program goals and milestones.

Management Structure. The headquarters program manager will be located in the OAST Propulsion, Power, and Energy Division (RP). In addition to program management responsibilities the program manager will be responsible for carrying out coordination activities mentioned described below.

The Lewis Research Center (LeRC) will be the lead center for the Chemical Transfer Propulsion program. The roles of other participating centers will be established during the course of detail planning over the next several months. As mentioned previously, an intercenter/interagency technical advisory committee that was established under the R&T Base program will continue to function in that capacity.

There is currently an active ad hoc subcommittee under the Space Systems and Technology Advisory Committee (SSTAC) that is evaluating and assessing propulsion

candidates for planetary missions. The results of their assessment will be used in planning the Pathfinder propulsion programs.

Program Coordination. In addition to coordination with the Office of Exploration relative to mission studies, the program will be also be coordinated with the Office of Space Flight (OSF) as the future developer of space transfer vehicles, and with the Office of Space Science and Applications (OSSA) in order to incorporate unmanned planetary mission drivers into propulsion technology requirements.

Coordination with DOD agencies will be maintained through normal program coordination activities, including the Joint Army, Navy, NASA, Air Force (JANNAF) Interagency Propulsion Committee, and the NASA/AF Space Technology Inter-dependency Group (STIG). In addition, a technical advisory committee supporting the project manager, will have an active air force member.

Resources. Projected resource requirements for this activity for fiscal years 1989 through 1993 are approximately $64 million. Resources allocated in FY 1989 are $4 million.

Section 5.2
High-Energy Aerobraking

5.2.1 Technology Requirements

NASA's planning for the future exploration of the solar system includes both piloted and robotic missions to Mars. The success of these as well as other planetary missions will depend upon maximizing the non-propellant mass for the mission in low Earth orbit (LEO), on the planetary surface, and for return to Earth. All of these are limited by current launch vehicle capabilities. A key enabling technology that promises to increase the payload-to-propellant mass ratio is "high-energy aerobraking". Through the development and use of aerobraking techniques, rather than retropropulsion, to achieve deceleration for orbit modification (i.e., transition from a transfer orbit to a circular orbit), substantial payload-to-propellant advantages will be realized. Aerobraking techniques may be utilized at either the target (for example, Mars), if the planet has an atmosphere, or at Earth return.

In the case of a Mars rover and sample return mission, the use of aerobraking at Mars could reduce total LEO mass requirement by fifty percent (50 %) over an all-propulsive Mars orbit insertion. The case for a piloted Mars mission is more complex, and the mass savings depends on the mission launch date and whether the vehicle is configured for zero gravity or for artificial gravity during transit. Given a zero gravity spacecraft configuration, the required mass to LEO for an all-propulsive mission would be two-to-four million pounds, compared with one-to-two million pounds for an aerobraking mission. The propellant mass savings and increased payload capability associated with aerobraking is very significant.

Although Earth's atmosphere is well characterized, uncertainties exist regarding variations in the properties of the atmosphere of Mars (and other planets). However, round-trip-light-time (RTLT) communications delays will preclude the possibility of effective ground-based adjustments of planetary aerocapture operations. In the case of robotic Mars mission, RTLT delays can be on the order of twenty minutes. Therefore, planetary aerocapture (e.g., at Mars) will require on-board, real-time GN&C capabilities that

can adapt to atmospheric uncertainties.

5.2.2 Technology Assessment

At present, no validated aerobraking capability exists. Apollo and Shuttle experiences, based on low and mid L/D (lift over drag) simple blunt configuration operating over narrow reentry corridors, provide a limited database relative to aeromaneuvering and/or aerobraking techniques. The two robotic Viking spacecraft that landed safely on Mars in 1976 did not have the capability to be precisely targeted at sites on the surface. This limitation would increase the risk and sharply reduce the scientific return of a piloted or robotic Mars mission. The Aeroassist Flight Experiment (AFE) will provide a database aimed at validating aerobraking for GEO and lunar return conditions/ This will be a significant step toward understanding aerobraking at conditions compatible to Mars entry velocity.

However, technology issues will still need to be resolved in a number of areas. The effects of long-term exposure of TPS materials to the space environment have not been precisely defined. In addition, advanced TPS designs (ablative, volume reflecting, etc.) that will accommodate very high velocity/high enthalpy flow conditions have not be adequately evaluated or developed.

In another area, the ability to handle "new" atmospheric constituents such as carbon dioxide, nitrogen, and argon has not been incorporated into current CFD codes. Gas chemistry models which can provide accurate prediction of aerodynamic and aerothermal loads in these environments are not yet being developed.

The ability to identify and compensate for large variations and fluctuations in both Earth and Mars atmospheric constituents and densities is needed. This will reduce the burden carried by the real-time, fault-tolerant, adaptive GN&C and flight mechanics systems.

Conceptual illustration of three classes of planetary aerobraking problems

In general, mission requirements and system design trades for piloted and robotic missions involving planetary entry aeromaneuvering and high-speed Earth reentry are not well-defined or understood.

Military capabilities for ballistic missile reentry and GN&C are sophisticated and well-demonstrated. However, the mission characteristics of solar system exploration aerobraking applications at Earth (e.g., a large piloted spacecraft) - and the

requirement for aerobraking at other planets - limit the *a priori* application of those technologies to civil space missions.

5.2.3 Program Description

The program will be planned and implemented in two broadly defined phases. The first will be a technology development phase which will result in the definition of selected aeroassist vehicle concepts and the definition of a flight experiment. The second phase will be a technology demonstration phase culminating in a high-energy aerobraking flight experiment.

The goal of phase I of the Pathfinder High-Energy Aerobraking Program is to develop the enabling technology base required to perform high-velocity aerocapture and aeromaneuvering, with resultant substantial reductions in mission LEO mass requirements. In order to achieve this goal, the program will be designed to achieve the following objectives:

(1) Establish mission constraints and requirements for planetary aerobraking (including aerocapture, aeromaneuvering entry, and orbit-to-orbit aerobraking)

(2) Develop and improve Computational Fluid Dynamics (CFD) codes for prediction of aerodynamic and aeroheating environments for planetary, and high-energy Earth, aerobraking,

(3) Develop and validate fault-tolerant GN&C technology for planetary and high-energy Earth aerobraking.

(4) Evaluate advanced Thermal Protection System (TPS) materials and designs.

In addition, requirements and concepts will be formulated for potential technology flight experiments to validate high-energy aerobraking at Earth return.

Overall vehicle configuration analyses and system design trades - which will be used to integrate discipline objectives - will be supported by appropriate ground testing. As a result of the above efforts, baseline vehicle concepts for both a piloted Mars mission and a Mars rover and sample return mission will be defined.

Flight validation in a "Planetary Return Flight Experiment" (PRFE) will be considered in phase II of the overall High Energy Aerobraking Program - and would be implemented in coordination with the Civil Space Technology Initiative (CSTI) Aeroassist Flight Experiment (AFE) Program. The information obtained from PRFE, complemented by the data obtained from AFE should provide a significant data base for a wide range of aerobrake applications.

The High-Energy Aerobraking Program will encompass a broad range of technical disciplines, each at varying levels of technology readiness and maturity. As a consequence, the technical approach to implementation will involve a family of related discipline-directed efforts, coordinated through a Headquarters/ Inter-Center working group (see the discussion below). Fundamental research in the areas of TPS and aero-/aerothermo- dynamics will be balanced against more focused efforts in GN&C algorithm and system development.

The program will be integrated through initial mission analyses and requirements studies, and through later system design trades and integration studies. These activities will also support the definition of a planetary return flight experiment.

Deliverables

PHASE I. By the early-to-mid 1990s,

critical technologies will be developed to the point of defining reasonable margins in aerobrake configurations, aerodynamics and aerothermodynamics, flight mechanics and controls, and TPS designs. Improved computational flow codes for both Earth and Mars atmospheres and engineering design capability will be available. TPS design trades will be completed and materials, cooling mechanisms, and structural concepts developed and evaluated. Advanced control algorithms will be established and adaptive GN&C systems validated. As a result of the above, baseline vehicle concepts for both a piloted Mars mission and a robotic mission (such as a Mars rover and sample return) will be defined.

PHASE II. By the mid-to-late 1990s, all key high-energy aerobraking/aeromaneuvering technologies will have reached a state of maturity that will permit a (high-energy) planetary return flight experiment (PRFE) to be defined and conducted. To the greatest extent possible, this experiment will be built on AFE experiences, flight data, and - where appropriate - flight hardware and instrumentation.

5.2.4 Management Plan

Work Breakdown Structure. This program is organized primarily along discipline lines, with specific cross-cutting tasks identified to integrate the discipline efforts.

Figure 5-2 provides a the preliminary work breakdown structure (WBS) for the program. This WBS will be revised and refined during the course of the next several months of detailed program planning.

Management Structure. The High-Energy Aerobraking Program will be managed by a Program Manager in the Aerodynamics Division of OAST (RF). Coordination between the various discipline efforts within the program will be provided through a High-Energy Aerobraking "management oversight committee" which is comprised of representatives from the several OAST discipline Divisions and the Space Directorate (RS). Responsibility for center assignments, project plan approval and funding allocation will remain with the RF Program Manager.

For each element of the program, a lead center will be assigned, and a Technology Project Manager appointed at that lead center. NASA centers will be designated to implement specific tasks within the technology project. Technology Project planning, integration and reporting will be performed by the Field Center Technology Project Manager.. Quarterly technology project reports will be submitted to OAST which track progress against Level 1 schedules and identify any problems, issues, or significant accomplishments.

Program Coordination. As noted above, this program will be coordinated with the on-going CSTI AFE program. The program will be more generally coordinated with appropriate personnel in the Office of Space Flight (as indicated in the Management Structure provided below). The program will also be coordinated with the OAST Power and Propulsion Division (in particular in the area of vehicle configuration definition).

In addition to mission analyses and requirements definition within the program, the High-Energy Aerobraking Program will be coordinated with (1) the piloted exploration mission definition studies of the Office of Exploration (OEXP), and (2) the Mars rover and sample return mission studies being conducted by OSSA. Specific mission studies or opportunities for mission

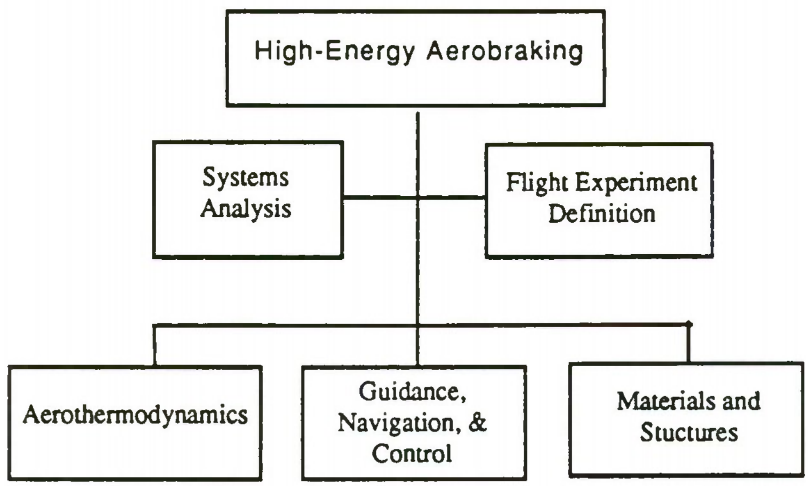


Figure 5-2
Work breakdown structure for the Pathfinder High-Energy Aerobraking Technology Project

enhancements through technology applications will be recommended to those offices.

This program will also seek coordination with space computing technology developments because some approaches may require a real-time, on-board processing capabilities.

This program will be coordinated with the other programs in Project Pathfinder through the respective Headquarters Program Managers. In particular, the GN&C aspects of this program will be coordinated with the corresponding areas of the Autonomous Lander Program and the Autonomous Rendezvous and Docking Program.

Coordination will be maintained with the relevant aspects of Department of Defense (DoD) programs.

Resources. Resource requirements for this activity for fiscal years 1989 through 1993 are approximately $46 million. The resource allocation for FY 1989 is $1.5 million.

Section 5.3
Cargo Vehicle Propulsion

5.3.1 Technology Requirements

The cost--which is proportional to the mass--of placing any spacecraft in low Earth orbit (LEO) is a major fraction of the total cost of a mission. Increasingly, propellant is becoming the dominant mass for NASA space missions. For example, in the case of the Galileo mission, propellant accounts for forty-three (43) percent of the total mass of

the spacecraft in LEO. For the more challenging Comet Rendezvous/Asteroid Flyby (CRAF) mission, chemical propellant makes-up seventy-six (76) percent of the LEO mass of the spacecraft.

The still more challenging missions that are being considered for the future--such as Mars--will place even greater demands on spacecraft propulsion system technology.

Studies have shown that for a "cargo vehicle" supporting a piloted mission to Mars, high performance electric propulsion with a specific impulse over 4000 sec at multi-megawatt power levels can offer major reductions in total propellant mass requirements--while still providing acceptable transit time performance. Compared with a chemically-propelled (cryogenic hydrogen/ oxygen) cargo vehicle, using aerocapture at Mars, a non-aerobraking, high performance electric propulsion vehicle could reduce total mission mass required in LEO by an amount equivalent to at least three Heavy Lift Launch Vehicles (HLLVs). The reduction in launched mass is obviously even greater for a non-aerobraking, completely propulsive chemically propelled cargo vehicle.

High specific impulse clearly offers propellant mass savings. However, in order to exploit that benefit practically, it is essential that the overall vehicle exhibit acceleration levels--and resultant transit times--sufficient to meet acceptable overall mission timeframes. This requirement necessitates low specific mass and high efficiency propulsion in order to keep low power system mass. High total impulse and high power capability per engine is also needed in order to accomplish mission propulsion system performance requirements with an acceptable number of individual engines.

5.3.2 Technology Assessment

At the present time, the only operation uses of electric propulsion have been low power systems used to perform satellite station-keeping functions. Since specific impulses (Isp) over 4,000 sec are of interest for Pathfinder, electrothermal systems such are arcjets are not adequate even with hydrogen propellant (Isp < 1,500 sec). Advanced concepts--such as electrodeless thruster systems--may ultimately provide the desired characteristics, but do not have sufficient technical maturity to be considered during the initial years of Pathfinder.

Ion engines have demonstrated specific impulses from less than 2,000 sec to more than 10,000 sec, thrust efficiencies to over seventy-five percent (75 %), and total thrust impulses as high as 10^6 newton-seconds for ten kilowatt (10 kW) class thrusters. Key issues are scale-up of ion acceleration subsystems for high power operation, increasing the power density to reduce the number of engines required, and thrust or life.

Magnetoplasmadynamic (MPD) propulsion technology is generally less advanced than ion systems. Power levels of five megawatts (5 MW) have been demonstrated in a pulsed power mode, but levels of only about 250 kW have been demonstrated for steady power. Most of the efficiency data fall into the fifteen-to-thirty percent (15-to-30 %) range, although some data for hydrogen and lithium propellants approach fifty percent (50 %) efficiency at very low power levels. Higher efficiencies and specific impulses are generally obtained with applied magnetic fields, but a fundamental theoretical understanding of this mode of operation is lacking. The highest total impulse demonstrated is 10^6 Newton-Seconds, at about twenty-five kilo-

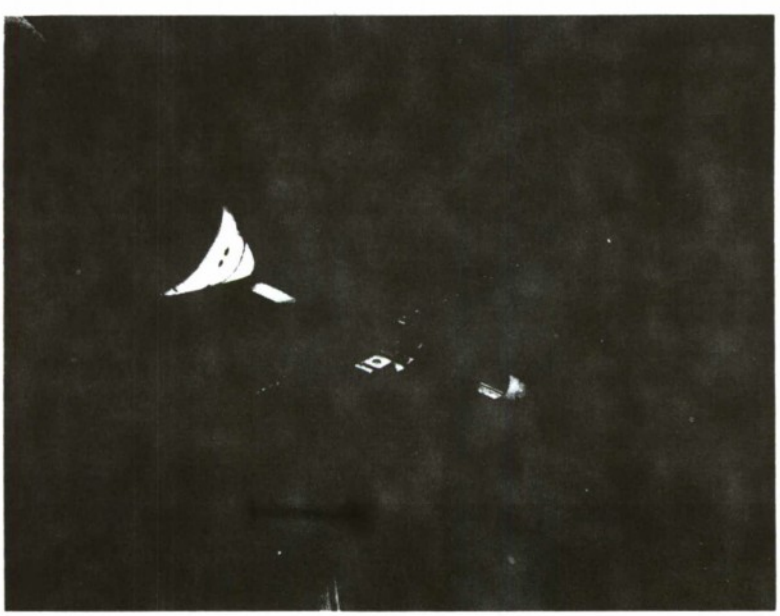
watts (25 kW). Key technology issues are thruster efficiency and life.

Facility background composition and pressure have been shown in some cases to have a very significant (factor greater than two) impact on measured performance. The impact of facility effects and the availability of enough high-fidelity ground test facilities are serious issues in the further development of high-power, high-performance electric propulsion systems.

5.3.3 Program Description

The Pathfinder Cargo Vehicle Propulsion Program will establish the feasibility and practicality of electric propulsion for piloted and robotic solar system exploration. The performance objectives of the program are: high specific impulse--over 4,000 sec, high efficiency--over sixty percent (60 %), and acceptable life. The electric propulsion technologies developed must also be scalable to multi-megawatt power levels. Sufficient durability will be targeted to enable a total impulse on the order of 10^8 newton-seconds per engine. Following preliminary development and testing, the most promising candidate thruster (ion or MPD) will be selected for further development.

The Cargo Vehicle Propulsion program will concentrate on performance and critical feasibility issues for the candidate thrusters. The first step will be to assess facility impacts on high-fidelity performance and durability data. Reliable short-term, in-situ methods of evaluating life issues will be developed along with the required facility capabilities, so that performance limits can be established for each thruster. Parallel thruster technology efforts will be performed for both self-field and applied-field MPD thrusters as well as ion engines. It is necessary to devote most of the resources early in the program to MPD development, because of its much greater technical uncertainties. Power processor technology will be directed to provide laboratory-class hardware. Supporting thermal and systems analyses will be included in the program, while mission studies will be provided from outside sources.



A nuclear-electric-propulsion driven cargo vehicle enters Mars' orbit

A three-phase program is envisioned. Phase I will cover the first five years of the effort. It will be devoted to establishing feasibility and practicality and will culminate in selection of the most promising of several

candidate electric propulsion concepts for further development. Phase I will be completed at the end of 1993.

Phase II will be a five-year focussed technology program that will demonstrate performance and life at high power levels and define requirements for a technology flight demonstration. If required, Phase III will be a flight validation of high-performance, high power electric propulsion technology.

5.3.4 Organization and Management

Work Breakdown Structure. A work breakdown structure (WBS) for the program is shown in Figure 5-3. This WBS is applicable to Phase I of the program, consistent with the technical approach described above. This WBS will revised and refined during the course of detailed planning during the next several months.

Management Structure. The program will be managed by a program manager in the OAST Propulsion, Power and Energy Division (RP).

The Lewis Research Center (LeRC) will act as the lead center for the program, with responsibility for technical integration and reporting; this function will be performed by the Low Thrust Propulsion Branch. Responsibility for assignment of participating center responsibilities and resource allocation decisions will remain with the OAST element program manager. Program efforts will be implemented by LeRC and the Jet Propulsion Laboratory (JPL).

Program Coordination. In addition to coordination with the Office of Exploration

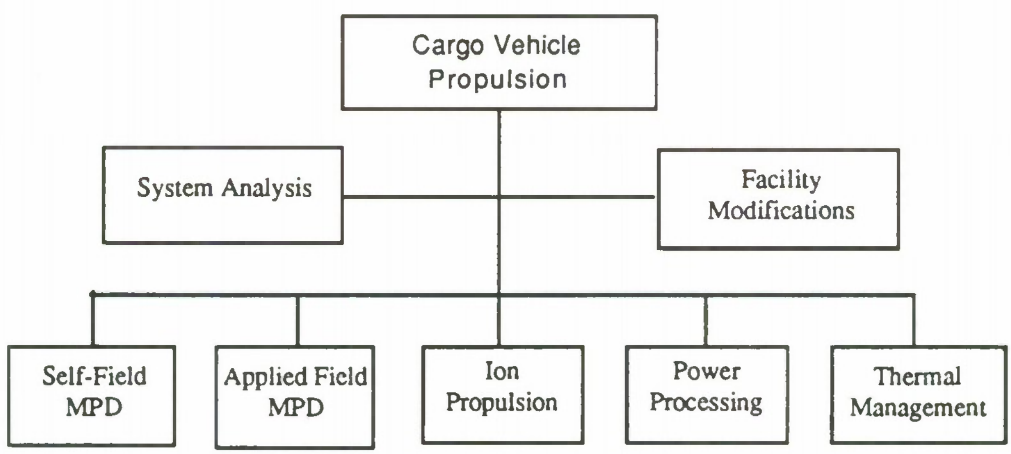


Figure 5-3
Work breakdown structure for the Pathfinder Cargo Vehicle Proplsion Technology Project

(OEXP) and the Office of Space Science and Applications (OSSA), the Cargo Vehicle Propulsion program will be coordinated with related programs in Project Pathfinder--including the Space Nuclear Power Program (SP-100)--and with related national activities, such as those within the Strategic Defense Initiative Organization (SDIO).

The program will be supported by and coordinated with mission studies conducted by the LeRC Advanced Systems Analysis Office (ASAO) for OEXP and planetary mission studies conducted by the Advanced Systems Analysis Group at the Jet Propulsion Laboratory (JPL) for OSSA.

Resources. Project resource requirements for the Cargo Vehicle Propulsion Technology Project for fiscal years 1989 through 1993 are approximately $16 million..

Chapter 6
Mission Studies

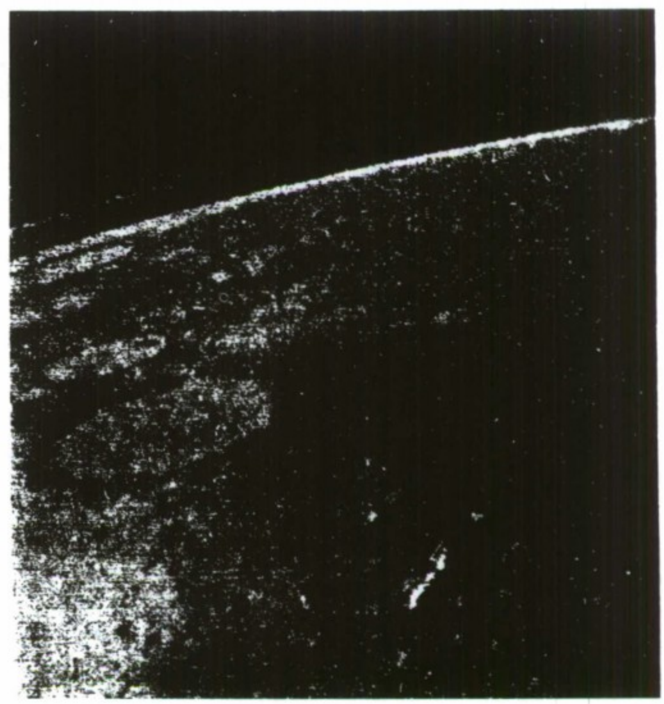
NASA is currently conducting several solar system exploration mission studies activities. The Office of Exploration (OEXP) is examining options for human exploration, while the Office of Space Science and Application's (OSSA's) solar system Exploration Division is studying future robotic exploration missions. Studies of robotic precursors to human missions - such as a Mars rover and sample return mission - are being jointly evaluated by OEXP and OSSA.

Section 6.1
Introduction

The mission studies being conducted by OEXP are extending the preliminary mission definition results described in the 1987 report Leadership and America's Future in Space by Dr. Sally K. Ride. OEXP's mission studies will provide greater understanding of the Leadership report's "bold new initiatives" and will explore other potential options.

This detailed understanding of each mission and the various options necessary to accomplish it are essential prerequisites to the selection and advocacy of a civil space leadership initiative. Studies of human mission options will also identify the scientific opportunities that can be supported by each mission and the requirements those opportunities place on the mission scenarios. Finally, OEXP's mission studies will identify and quantify the technology requirements for each mission option and will conduct systematic trade-off studies between alternate technologies.

The mission studies will include mission-level assessments and focused activities in areas such as in-space transfer vehicles, operations requirements at various nodes such as Earth, Mars, and Lunar orbits, and Mars and Lunar surface operations. In addition, the studies will assess the leverage inherent in systems and technologies for power, propulsion, life support, and automation & robotics.



Other offices in NASA, such as the Office of Space Station (OSS) and the Office of Space Flight (OSF) are examining how their programs and plans would be affected by future solar system exploration missions.

Section 6.2
Human Exploration Case Studies

At the present time, OEXP mission studies are focused on four specific "case studies" of potential human exploration initiatives. These are: (1) a human expedition to Phobos (a moon of Mars), (2) a human expedition to the surface of Mars, (3) installation and operation of human-tended scientific observatories on the Moon, and (4) an evolutionary extension of human presence - starting with an outpost on the Moon and building toward missions to Mars.

Through these human exploration case studies, which are partially funded by the current Path-finder "Mission Studies" program area, OEXP is identifying and clarifying the various program planning changes and technology requirements that NASA must satisfy in order to achieve those ambitious civil space objectives.

6.2.1 Human Expedition to Phobos

This case study examines the options for the first and/or fastest human mission to the Mars system. An initiative following along the lines delineated in this case study would result in a human landing on this moon of Mars by the 2003 timeframe. In terms of impacts on other NASA programs, this case has identified only minimal requirements that would be imposed on an Earth-orbiting Space Station. ETO launch capabilities would require substantial augmentation to meet the preliminary needs that have been identified.

Technology requirements to achieve the objectives identified by the Phobos case study are minimal; but include: (1) assembly and integration of vehicle systems in Earth orbit, (2) extravehicular activity (EVA) suits and systems for Phobos proximity operations, (3) In-Space cryogenic fueling of mission vehicles, and (4) telerobotic "rovers" that would be landed on the surface of Mars, and controlled by astronauts in Mars' orbit. Aerobraking is being considered as a possible mission option.

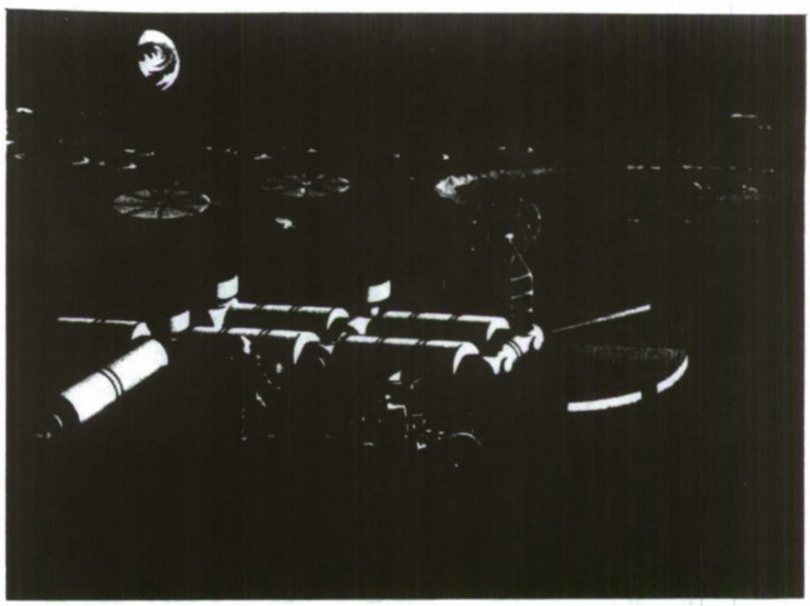
6.2.2 Human Expeditions To Mars

This case study examines the options for the first human mission to the surface of Mars. A future initiative following this sort of mission approach would result in a human landing on Mars by the 2008 timeframe.

This case would involve substantial requirements for ETO launch capabilities, and an Earth-orbiting Space Station, including both mission staging and pre-mission research and development of essential technology and determining the effects of long-duration space flight on humans.

Technology requirements to achieve the objectives that have been identified by the Mars expedition case study include: (1) telerobotic assembly and automated integration of vehicle systems in Earth orbit, (2) extravehicular activity (EVA) suits and systems for Mars surface operations, (3) In-space cryogenic fueling of mission vehicles, (4) interplanetary aerocapture technologies, and (5) advanced space propulsion systems.

As a potential precursor to a piloted flight, a robotic mission to Mars would involve semi-autonomous "rovers" that would be landed on the surface of Mars, and controlled from Earth.



6.2.3 Lunar Observatories

The "Lunar observatories" case study examines the options depoyment and operation of a major astronomical observatory on the Moon. This case has examine issues associated with an initial mission by the year 2000 timeframe; it would involve both some increase in ETO capabilities some requirements for an Earth-orbiting Space Station.

To achieve the objectives that have been identified through the Lunar Observatories case study, technology requirements include (1) automated integration of vehicle systems in Earth orbit, (2) extravehicular activity (EVA) suits and systems for the Lunar surface, and (3) surface power systems (potentially including space nuclear power and mobile power for Lunar rover and equipment).

As a potential precursor to a piloted flight, robotic missions to the Moon might involve Lunar orbiters and semi-autonomous or teleoperated rovers that would be landed on the surface of Mars, and controlled from Earth.

6.2.4 Evolution: Lunar Outpost to Early Mars Outpost

This case study examines the options for an evolutionary program that would start with a return to the Moon to build an outpost and lead ultimately to an outpost on the surface of Mars. By assumption, this case study limits launch capability projects. That assumption constrains the rate at which the

case develops, forcing innovative approaches. A potential initiative constructed along the lines explored in this case study would result in a permanent, self-sustaining human presence beyond low Earth orbit (LEO). This case would involve substantial requirements for an Earth-orbiting Space Station, and more advanced orbiting "nodes", including both mission staging and pre-mission research on the effects of long-duration flight on humans.

Technology requirements to achieve the objectives of the evolutionary expansion case study are very broad. These requirements include: (1) telerobotic assembly and automated integration of vehicle systems in Earth orbit, (2) extravehicular activity (EVA) suits and systems for Lunar and Mars surface operations, (3) In-space cryogenic fueling of mission vehicles, (4) reusable interplanetary aerocapture technologies, (5) advanced space propulsion systems, including nuclear electric propulsion, (6) in situ resource processing (and propellant production), and (7) advanced life support systems.

As a precursor to a piloted missions, robotic missions to the Moon or Mars would involve semi-autonomous "rovers" that would be landed on the planetary surface and controlled from both Earth and orbit.

Section 6.3
Robotic Solar System Exploration Mission Studies

NASA has a long-standing tradition of excellence in robotic Solar System exploration. In the future, NASA plans to continue that tradition, both to further our attempts to understand our planetary system, its origin, and its evolution, and also to provide robotic precursors to later human exploration expeditions.

A broad assortment of robotic mission options are currently under consideration. These span the gamut from more near-term opportunities (with little or no needs for Pathfinder technologies), to sophisticated and ambitious far-term mission concepts that may involve returning samples to Earth for intensive study (with strong technology requirements).

6.3.1 **Near-Term Mission Options**

Nearer-term options include applications of the "Mariner Mark II" spacecraft series. These are the Comet Rendezvous Asteroid Flyby (CRAF) mission, which would study both a Main Belt asteroid and a comet; and the Cassini mission, which would orbit Saturn and provide comprehensive studies of its largest moon, Titan.

Both of these missions are slated for a new start decision in the 1990-1991 timeframe,

and would be built and launched by the mid-to-late 1990s. Although exciting, both of these missions will probably be implemented before Pathfinder technologies are available for application.

6.3.2 Sample Return Missions

Farther out on the horizon, a pinnacle of robotic exploration will be reached through one or more planetary surface sample return missions. The primary options for such mission concepts are the Comet Nucleus Sample Return (CNSR) mission, and a Mars Rover and Sample Return (MRSR) mission. Both of these missions will require advances in automation and robotics, *in situ* analysis and sample preservation, and in space transfer technologies, such as aerocapture at Earth return. (The MRSR mission concept is discussed in more detail below.)

Either of these missions could be started in the mid-to-late 1990s timeframe, and could be built and launched by the early part of the next century.

Mars Rover and Sample Return (MRSR). The MRSR mission concept is being studied by both the Office of Exploration and the Office of Space Science and Applications. One or more robotic missions to Mars represent both a scientific opportunity, but - and perhaps more importantly - also an technology demonstration opportunity. Unlike the Apollo Program, a piloted Mars mission program will not have the luxury of multiple trial flights, during which various technologies and new capabilities could be proven prior to a commitment to a landing on the surface. Because of the distances and resultant flight times involved, a piloted mission to Mars may only be preceded by one or more robotic flights such as the MRSR concept.

Technologies that could be validated during a robotic mission include aerocapture at Mars, precision guidance and hazard avoidance during landing, surface mobility systems, ascent propulsion and rendezvous in Mars orbit, and successful high-energy aerocapture at Earth return.

6.3.3 Outer Planet Missions

Future mission options will also include follow-on missions to the currently planned Galileo spacecraft that will orbit Jupiter, and the projected Cassini mission to Saturn. Future outer planet missions could involve orbiters of the far outer planets (Uranus and Neptune) or a flyby of the solar system's most distant goal: the Pluto-Charon system.

Technology requirements for such missions include those which are common to many others, such as planetary aerobraking, advanced space communications (e.g., optical communications), increased spacecraft on-board computing and autonomy, and higher levels of on-board power. They also include more mission-specific technology options, such as nuclear electric propulsion (NEP), which would substantially augment mission capabilities or reduce mission durations.

Pathfinder

Chapter 7

Strategic Perspective

Pathfinder will allow NASA's Office of Aeronautics and Space Technology to develop critical capabilities to enable future missions of solar system Exploration. This goal will be pursued vigorously over several years, guided by stable technology objectives against which real progress can be made and measured. Pathfinder must nevertheless be responsive to the changing needs of the Agency. Without constraining the program to the technology needs of any single system or mission concept, year-to-year planning for Pathfinder must occur in a strongly-grounded strategic context.

That strategic perspective is provided by a projection of potential solar system exploration missions. From that projection, technologies are identified that will either enable or significantly enhance those missions. As noted in Chapter 6, the missions include piloted missions (such as a mission to Mars, or the beginning of operations on the surface of the Moon), and robotic missions (such as robotic precursors to human missions or ambitious sample return and outer planet missions). The technologies needed for those missions fall broadly into the four thrusts of Pathfinder, and are crystallized within those thrusts into elements that will meet critical functional mission needs.

This approach, applied to annual program planning, will allow Pathfinder to balance the need for stability in research programs against the detailed technology needs of specific, but sometimes rapidly-changing, mission designs. Moreover, as Pathfinder technologies reach maturity and are adopted by early mission users, this strategic perspective on the technology needs of solar system exploration will permit the elegant and timely evolution of detailed element program goals and objectives.

Pathfinder technologies will be developed for future civil space missions. At the same time, however, those technologies will undoubtedly find broader applications outside of NASA, both on Earth and in space.

For example, in the Surface Exploration program area, Planetary Rover technologies, such as autonomy and mobility, will have numerous terrestrial applications either for National defense, or for high-risk civil uses such as toxic waste disposal or fire fighting. Sample Acquisition, Analysis, and Preservation technologies, such as tools, sensors and expert systems, may find applications in remote resource exploration,

in enhanced conventional mining operations, or in low-cost, small-size laboratory instruments. Also, Autonomous Lander technologies, such as the real-time integration of data from multiple sensors, will benefit aeronautics and aircraft safety through risk-reducing autonomy and sensor systems.

In-Space Operations technologies will also find wide applications in private space ventures and in terrestrial endeavors. For example the Resource Processing Pilot Plant program will develop integrated and highly automated mechanical and chemical processing plant systems. Also, the capability to perform In-Space Assembly and Construction will be of great value to future commercial GEO communications satellites.

Humans-in-Space research and technology will provide valuable information about the impact on productivity of interrelationships between workers and their environments in a high-technology setting. Similarly, studies of physical-chemical and bioregenerative life support systems will produce important new information on how ecological systems work - and why they fail.

Lastly, space transfer technologies such as advanced chemical propulsion and aerobraking, although specialized for space applications, will provide further engineering expertise in materials and structures, and the use of aero- and aerothermo- dynamic modeling, and design for high-speed aircraft and spacecraft.

Across a wide spectrum, during the coming decade Pathfinder can push American technology forward. In the same way that the Apollo program did during the 1960's, Pathfinder represents a strategic investment in research and technology that is critical to the civil space program and to the Nation.

Glossary of Acronyms

A&R	Automation & Robotics
AFE	Aeroassist Flight Experiment
AI	Artificial Intelligence
ALS	Advanced Launch System
A-OTV	Aeroassisted-OTV
ARC	Ames Research Center
ASEB	Aeronautics and Space Engineering Board
BNI	Bold New Initiative
CNSR	Comet Nucleus Sample Return
COSMIC	Coherent Optical System of Modular Imaging Collectors
CRAF	Comet Rendezvous and Asteroid Flyby
CSTI	Civil Space Technology Initiative
DSN	Deep Space Network
DoD	Department of Defence
DoE	Department of Energy
E	OSSA
EB	OSSA Life Sciences Division
EL	OSSA Planetary Exploration Division
ELV	Expendable Launch Vehicle
EOS	Earth Observing System
ETO	Earth-To-Orbit
EVA	Extra-Vehicular Activity
FY	Fiscal Year
GPBS	Gigabytes per second
GEO	Geostationary Earth Orbit
GN&C	Guidance, Navigation, and Control
GSFC	Goddard Space Flight Center
HLLV	Heavy Lift Launch Vehicle
Isp	Specific Impulse

ISPP	In-Situ Propellant Production
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
kg	Kilogram
KSC	Kennedy Space Center
kWe	Kilowatts-Electric
kWt	Kilowatts-Thermal
LANL	Los Alamos National Laboratory
LaRC	Langley Research C enter
L/D	Lift-to-Drag Ratio
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LDR	Large Deployable Reflector
LGO	Lunar Geoscience Observer (Mission)
LH	Liquid Hydrogen
LOX	Liquid Oxygen
LTEF	Laser Technology Experiment Facility
m	Meter
Mbps	Mega-bits per second
mm	Millimeter
μm	Micrometer
MO	Mars Observer (Mission)
MOA	Memorandum of Agreement
MPD	Magnetoplasmadynamic (Thruster)
MPFP	Materials Processing Factory Platform
MR	Mars Rover (Mission)
MRSR	Mars Rover/Sample Return (Mission)
MSR	Mars Sample Return (Mission)
MSFC	Marshall Space Flight Center
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NAS	National Academy of Sciences

NASP	National Aerospace Plane
NCOS	National Commission On Space
NEP	Nuclear Electric Propulsion
NRC	National Research Council
OAST	Office of Aeronautics and Space Technology
OEXP	Office of Exploration
OMV	Orbital Manuevering Vehicle
OSF	Office of Space Flight
OSO	Office of Space Operations
OSS	Office of Space Station
OSSA	Office of Space Science and Applications
OTA	Office of Technology Assessment
OTV	Orbital Transfer Vehicle
PhD	Phobos/Deimos
PRFE	Planetary Return Flight Experiment
R	OAST
R&T	Research and Technology
RC	OAST Information Sciences and Human Factors Division
RF	OAST Aerodynamics Division
RF	Radio Frequency
RM	OAST Materials and Structures Division
RP	OAST Propulsion, Power, and Energy Division
RS	OAST Space Directorate
RTG	Radioisotope Thermoelectric Generator
RX	OAST Flight Projects Division
S	OSS
SAAP	Sample Acquisition, Analysis, and Preservation
S/C	Spacecraft
sec	Second(s)
SP-100	Space Power-100
S/S	Space Station
SSEC	Solar System Exploration Committee
SSTAC	Space Systems Technology

STS	Space Transportation System
TPS	Thermal Protection System
U.S.	United States (of America)
VLBI	Very Long Baseline Interferometry
WBS	Work Breakdown Structure
Z	OEXP

Recommended Reading

Pioneering the Space Frontier: The Report of the National Commission on Space; National Commission on Space (NCOS); (New York: Bantam Books). 1986.

Leadership and America's Future in Space. A Report to the Administrator; Ride, S.K.; (Washington, D.C.; NASA). August 1987.

Key Technologies for the 1990s--An Overview; Aerospace Industries Association of America (AIA); (Washington, D.C.: AIA). November 1987.

Space Technology to Meet Future Needs; National Research Council: Washington, D.C.: National Academy Press). 1987.

Manned Mars Missions--A Working Group Report; Duke, M.B. and Keaton, P.W.; (Huntsville, Alabama: NASA Marshall Space Flight Center, with Los Alamos Laboratories). May 1986.

Mars Rover Technology Workshop Proceedings; Mankins, J.C., editor; (Pasadena, California: Jet Propulsion Laboratory, JPL D-4788). April 28-30, 1987.

Preliminary Survey of 21st Century Civil Mission Applications of Space Nuclear Power; Mankins, J.C., et al.; (Pasadena, California: Jet Propulsion Laboratory, JPL D-3547). March 1987.

Project Pathfinder--Research and Technology to Enable Future Space Missions; OAST; (Washington. D.C.: Brochure/JPL 400-330. December 1987.

Prerequisite Requirements for Exploration Class Missions; Office of Exploration (OEXP); (Washington, D.C.: NASA OEXP Document). 1988.

Solar System Exploration - Discovering Our Origins and Destiny; Office of Space Science and Applications (OSSA), Solar System Exploration Division (EL); (Washington, D.C.: NASA OEXP Brochure).

Advanced Mission Concepts for Outer Planets Exploration, a report prepared for the OSSA Solar System Exploration Division; Science Applications Internation Corporation (SAIC); (Schramsberg, Illinois: SAIC, Report No. 86/1036, Contract NASW-3622). January 1986.

Piloted Sprint Missions to Mars, a report prepared for the Office of Exploration; SAIC; (Schramsberg, Illinois: SAIC, Report No. 87/1901, Study No. 1-120-449-M26, Contract NASW-4214). November 1987.

Recommended Reading

Planetary Exploration Through Year 2000--A Core Program, Part One of a Report by the Solar System Exploration Committee of the NASA Advisory Council; Solar System Exploration Committee (SSEC); (Washington, D.C.: NASA). 1986.

Planetary Exploration Through Year 2000--An Augmented Program, Part Two of a Report by the SSEC of the NASA Advisory Council; SSEC; (Washington, D.C.: NASA). 1986.

PATHFINDER

APPENDIX B

NASA - Wide Points of Contact for Space R&T Programs

Office of
Aeronautics and
Space
Technology

R&T BASE / CSTI / PATHFINDER
KEY POINTS OF CONTACT

Technology for Future NASA Missions
An AIAA/NASA OAST Conference

September 12-13, 1988

NASA AMES RESEARCH CENTER

KEY CONTACTS

OAST

	R&T BASE	CSTI	PATHFINDER
AEROTHERMODYNAMICS JAMES ARNOLD (415) 694-5265	X	X	X
AUTONOMOUS SYSTEMS HENRY LUM (415) 694-6544	X	X	X
FLIGHT SYSTEMS			
ADVANCE CONTROLS/GUIDANCE DALLAS DENERY (415) 694-5427			X
HUMAN IN SPACE ACTIVITIES			
ARTIFICIAL GRAVITY/ADV. COUNTER MEAS. MALCOLM COHEN			X
CLOSED LOOP LIFE SUPPORT JAMES LAWLESS (415) 594-5900	X		X
EVA/SUIT BRUCE WEBBON (415) 694-5984	X		X
HUMAN PERFORMANCE MICHAEL SHAFTO (415) 694-6170	X	X	X

NASA AMES RESEARCH CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
SPACE FLUID DYNAMICS SANFORD DAVIS (415) 694-4197	X		X
SPACE SENSORS CRAIG McCREIGHT (415) 694-6549	X	X	
THERMAL PROTECTION SYSTEMS HOWARD GOLDSTEIN (415) 694-6103	X	X	X
PATHFINDER PROJECT LEWIS L. PEACH, JR. (415) 694-4951			X

NASA GODDARD SPACE FLIGHT CENTER

KEY CONTACTS

OAST

	R&T BASE	CSTI	PATHFINDER
ENERGY AND THERMAL R. McINTOSH (301) 286-3478	X		
MATERIALS R. MARRIOTT (301) 286-6882	X		
CONTAMINATION J. TRIOLO (301) 286-8651	X		
SENSORS H. PLOTKIN (301) 286-6185	X	X	X
DATA SYSTEMS J. DALTON (301) 286-8623	X	X	
COMPUTER SCIENCE R. PRICE (301) 286-9041	X	X	
CONTROLS H. FRISCH (301) 286-8730	X		
SPACE FLIGHT R&T D. FRIEDMAN (301) 286-6242	X		

NASA GODDARD SPACE FLIGHT CENTER

KEY CONTACTS

OAST

	R&T BASE	CSTI	PATHFINDER
SYSTEMS ANALYSIS G. RODRIGUEZ (301) 286-6202	X		
ROBOTICS H. PLOTKIN (301) 286-6185		X	X
AUTONOMOUS SYSTEMS J. DALTON (301) 286-8623		X	
COMMUNICATIONS (LASER) M. FITZ MAURICE (301) 286-8942	X		X

NASA JOHNSON SPACE CENTER

KEY CONTACTS

OAST

	R&T BASE	CSTI	PATHFINDER
PRIMARY CONTACT FOR CENTER RESEARCH AND TECHNOLOGY PROGRAMS	X	X	X
MARK B. NOLAN (713) 282-1917			
HUMANS-IN-SPACE			
LIFE SUPPORT AND EVA/SUIT ALBERT F. BEHREND (713) 483-9241	X		X
HUMAN FACTORS BARBARA WOOLFORD (713) 483-3701	X		X
GUIDANCE, NAVIGATION, AND CONTROL KENNETH J. COX (713) 483-8224	X		X
THERMAL MANAGEMENT WILBERT E. ELLIS (713) 483-9108	X		X
AUTONOMOUS SYSTEMS KATHLEEN J. HEALEY (713) 483-4776		X	X

NASA JOHNSON SPACE CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
TELEROBOTICS CHARLES R. PRICE (713) 483-1523		X	X
PHOTONICS RICHARD D. JUDAY (713) 483-1486	X		X
AEROTHERMODYNAMICS ROBERT C. RIED (713) 483-6606		X	X
MATERIALS LUBERT J. LEGER (713) 483-8916	X		X
STRUCTURES DONALD C. WADE (713) 483-2876	X		X
SOFTWARE ENGINEERING KUMAR KRISHEN (713) 483-6777	X		
AEROBRAKING DONALD M. CURRY (713) 483-8865		X	X

NASA JOHNSON SPACE CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
SAMPLE ACQUISTION, ANALYSIS, AND PRESERVATION DOUGLAS P. BLANCHARD (713) 483-5151			X
AUTONOMOUS LANDER KENNETH J. BAKER (713) 483-2041			X
AUTONMOUS RENDEZVOUS AND DOCKING DON C. BROWN (713) 483-8241			X
IN-SPACE ASSEMBLY AND CONSTRUCTION REG B. BERKA (713) 483-8846			X
ORBITER EXPERIMENTS ROBERT SPANN (713) 483-3022	X		
RESOURCE PROCESSING PILOT PLANT DAVID S. McKAY (713) 483-5048			X

NASA LANGLEY RESEARCH CENTER

KEY CONTACTS

OAST

	R&T BASE	CSTI	PATHFINDER
SPACE ENERGY CONVERSION R&T R.R. NUNAMAKER (804) 865-2893	X		
PROPULSION R&T R.R. NUNAMAKER (804) 865-2893	X		
MATERIALS & STRUCTURES R&T C.P. BLANKENSHIP (804) 865-2042	X		
SPACE DATA & COMMUNICATIONS R&T J.F. CREEDON (804) 865-4915	X		
INFORMATION SCIENCES R&T W.D. MACE (804) 865-3745	X		
CONTROLS & GUIDANCE R&T J.F. CREEDON (804) 865-4915	X		
SPACE FLIGHT R&T R.R. NUNAMAKER (804) 865-2893	X		

NASA LANGLEY RESEARCH CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
SYSTEMS ANALYSIS R.R. NUNAMAKER (804) 865-2893	X		
NASP HYPERSONICS R&T-SPACE R.V. HARRIS, JR (804) 865-3285	X		
INTERDISCIPLINARY TECHNOLOGY R.W. BARNWELL (804) 865-2664	X		
ROBOTICS J.F. CREEDON (804) 865-4915		X	
AUTONOMOUS SYSTEMS J.F. CREEDON (804) 865-4915		X	
BOOSTER TECHNOLOGY R.R. NUNAMAKER (804) 865-2893		X	
SCIENCE SENSOR TECHNOLOGY W.D. MACE (804) 865-3745		X	

NASA LANGLEY RESEARCH CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
DATA: HIGH RATE CAPACITY W.D. MACE (804) 865-3745		X	
COFS/CSI J.F. CREEDON (804) 865-4915		X	
PRECISION SEGMENTED REFLECTORS C.P. BLANKENSHIP (804) 865-2042		X	
LONG DURATION EXPOSURE FACILITY R.L. JAMES, JR. (804) 865-4987			X
LASER IN-SPACE TECHNOLOGY EXPERIMENT R.R. NELMS (804) 865-4947			X
IN-SPACE ASSEMBLY & CONSTRUCTION C.P. BLANKENSHIP (804) 865-2042			X
HUMAN PERFORMANCE J.F. CREEDON (804) 865-4915			X
HIGH ENERGY AEROBRAKING R.R. NUNAMAKER (804) 865-2893			X
FAULT-TOLERANT SYSTEMS J.F. CREEDON (804) 865-4915			X

NASA LEWIS RESEARCH CENTER

KEY CONTACTS

OAST

	R&T BASE	CSTI	PATHFINDER
SPACE POWER			
SPACE ENERGY CONVERSION R&T HENRY BRANDHORST (216) 433-6149	X		
AUTONOMOUS SYSTEMS GALE SUNDBERG (216) 433-6152		X	
HIGH CAPACITY POWER JERRY WINTER (216) 433-6133		X	
SURFACE POWER (AND ROVER) JOHN BOZEK (216) 433-6166			X
SPACE NUCLEAR POWER JOHN SMITH (216) 433-6130			X
SPACE PROPULSION			
PROPULSION R&T LARRY DIEHL (216) 433-2438	X		
EARTH TO ORBIT PROPULSION SOL GORLAND (216) 433-2449		X	
CHEMICAL TRANSFER PROPULSION NED HANNUM (216) 433-2457			X

NASA LEWIS RESEARCH CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
SPACE PROPULSION (Cont'd)			
CARGO VEHICLE PROPULSION DAVID BYERS (216) 433-2447			X
SPACE ELECTRONICS			
SPACE DATA & COMMUNICATIONS R&T DENIS CONNOLLY (216) 433-3503	X		
SCIENCE SENSOR TECHNOLOGY JAMES DAYTON (216) 433-3515		X	
FAULT TOLERANT SYSTEMS CHARLES RAQUET (216) 433-3471			X

NASA LEWIS RESEARCH CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
MATERIALS			
MATERIALS R&T SALVATORE GRISAFFE (216) 433-3193	X		
STRUCTURES			
STRUCTURES R&T LESTER NICHOLS (216) 433-3213	X		
CYROGENICS			
NASP HYPERSONICS R&T (FUEL) NED HANNUM (216) 433-2457	X		
CYROGENIC FUEL DEPOT (AND FLIGHT EXPTS) EUGENE SYMONS (216) 433-2853	X		X
SPACE EXPERIMENTS			
SPACE FLIGHT R&T LYNN ANDERSON (216) 433-2874	X		
SYSTEM ANALYSIS	X	X	X
JOHN NIEBERDING (216) 433-5418			

NASA MARSHALL SPACE FLIGHT CENTER

KEY CONTACTS

OAST

	R&T BASE	CSTI	PATHFINDER
SPACE R&T			
PROPULSION			
NOZZLE DAVE SPARKS (205) 544-7111	X		
ENGINE FLOW FIELDS KLAUS GROSS (205) 544-2262	X		
OXYGEN-RICH COMBUSTION FRED BRAAM (205) 544-7055	X		
MANAGEMENT JACK MACPHERSON (205) 544-5936	X		
CONTROL AND GUIDANCE			
TECHNICAL HENRY WAITES (205) 544-1441	X		
MANAGEMENT DICK SCHOCK (205) 544-4060	X		

NASA MARSHALL SPACE FLIGHT CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
SYSTEM ANALYSIS			
TECHNICAL TBD		X	
MANAGEMENT JACK MACPHERSON (205) 544-5936		X	
AUTOMATION AND ROBOTICS			
ROBOTICS		X	
TECHNICAL E.C. SMITH (205) 544-3506		X	
MANAGEMENT JON HAUSSLER (205) 544-1762			
AUTONOMOUS SYSTEMS TECHNICAL MICHAEL FREEMAN (205) 544-5456		X	
MANAGEMENT JON HAUSSLER (205) 544-1762		X	

NASA MARSHALL SPACE FLIGHT CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
PROPULSION			
EARTH-TO-ORBIT			
COMBUSTION CHARLES CORNELIUS (205) 544-7130		X	
TURBOMACHINERY LUKE SCHUTZENHOFER (205) 544-1458		X	
SPACE MONITORING & CONTROL PAT VALLELY (205) 544-1440		X	
MANAGEMENT JAMES MOSES (205) 544-1747		X	
BOOSTER TECHNOLOGY			
HYBRID BEN SHACKELFORD (205) 544-7109		X	
PRESSURE FED CHARLES CORNELIUS (205) 544-6728		X	
MANAGEMENT JAMES CLARK (205) 544-6728		X	

NASA MARSHALL SPACE FLIGHT CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
VEHICLE			
AEROASSIST FLIGHT EXPERIMENT			
TECHNICAL TERRY GREENWOOD (205) 544-1585		X	
MANAGEMENT MICKEY ALLEN (205) 544-0104		X	
INFORMATION TECHNOLOGY			
SCIENCE SENSOR TECHNOLOGY			
TECHNICAL JAMES BILBRO (205) 544-3467		X	
MANAGEMENT JON HAUSSLER (205) 544-1762		X	

NASA MARSHALL SPACE FLIGHT CENTER

KEY CONTACTS (Cont'd)

OAST

	R&T BASE	CSTI	PATHFINDER
LARGE STRUCTURES & CONTROL			
CONTROL OF FLEXIBLE STRUCTURES			
TECHNICAL HENRY WAITES (205) 544-1441		X	
MANAGEMENT DICK SCHOCK (205) 544-4060		X	
IN-SPACE OPERATIONS			
IN-SPACE ASSEMBLY & CONSTRUCTION			
MECHANICAL JOINTS JOEL WILLIAMSEN (205) 544-7010			X
WELDING CHIP JONES (205) 544-2701			X
ASSEMBLY TOM BECHTAL (205) 544-7150			X
MANAGEMENT DICK SCHOCK (205) 544-4060			X

NASA JET PROPULSION LABORATORY

KEY CONTACTS

OAST

GUIDANCE, NAVIGATION, AND CONTROL
RICHARD KEY (818) 354-3060

STRUCTURES AND MATERIALS
RICHARD KEY (818) 354-3060

OPTICS
RICHARD KEY (818) 354-3060

PRECISION REFLECTORS
RICHARD KEY (818) 354-3060

CONTROL OF FLEXIBLE STRUCTURES
RICHARD KEY (818) 354-3060

POWER
ARTHUR MURPHY (818) 354-6457

PROPULSION
ARTHUR MURPHY (818) 354-6457

SYSTEMS ANALYSIS
ARTHUR MURPHY (818) 354-6457

IN-SPACE EXPERIMENTS
ARTHUR MURPHY (818) 354-6457

NASA JET PROPULSION LABORATORY

KEY CONTACTS (Cont'd)

OAST

AERODYNAMICS
ARTHUR MURPHY (818) 354-6457

DATA SYSTEMS
DAVID NICHOLS (818) 354-8912

COMPUTER SCIENCE
DAVID NICHOLS (818) 354-8912

INFORMATION SYSTEMS
DAVID NICHOLS (818) 354-8912

COMMUNICATIONS
WILLIAM RAFFERTY (818) 354-5095

SCIENCE SENSORS
VIRENDRA SAROHIA (818) 354-6758

MICROELECTRONICS
VIRENDRA SAROHIA (818) 354-6758

PHOTONICS
VIRENDRA SAROHIA (818) 354-6758

SUPERCONDUCTIVITY
VIRENDRA SAROHIA (818) 354-6758

NASA JET PROPULSION LABORATORY

KEY CONTACTS (Cont'd)

OAST

AUTOMATION AND ROBOTICS
GIULIO VARSI (818) 354-2992

CSTI PROGRAM

OAST

CSTI THRUST & ELEMENTS	OAST DIVISION	ELEMENT MANAGER	COORD. CENTER	CENTER MANAGER
ROBOTICS	RC	M. MONTEMERLO (202-453-2744)	JPL	GIULIO VARSI (818-792-2992)
AUTONOMOUS SYSTEMS	RC	M. MONTEMERLO (202-453-2744)	ARC	HENRY LUM, Jr. (415-464-6544)
EARTH TO ORBIT	RP	F. STEPHENSON (202-453-2853)	MSFC	ROBERT J. RICHMOND (205-544-6645)
BOOSTER TECHNOLOGY	RP	F. STEPHENSON (202-453-2853)	MSFC	ROBERT J. RICHMOND (205-544-6645)
AEROASSIST FLIGHT EXP.	RX	R. GUALDONI (202-453-2833)	MSFC	LEON B. ALLEN (205-544-1917)
SCIENCE SENSOR TECH.	RC	M. SOKOLOSKI (202-453-2847)	LaRC	FRANK ALLARIO (804-865-3601)
DATA: HIGH RATE/CAPACITY	RC	P. SMITH (202-453-2753)	LaRC	REGGIE HOLLOWAY (804-865-3541)
CONTROL OF FLEX. STRUCT.	RM	D. MULVILLE (202-453-2862)	LaRC	BRANTLEY R. HANKS (804-865-3058)
PRECISION SEG. REFLECTORS	RM	M. HIRSCHBEIN (202-453-2859)	JPL	EUGENE V. PAWLIK (818-792-0086)
HIGH CAPACITY POWER	RP	A.D. SCHNYER (202-453-2855)	LeRC	JERRY M. WINTER (216-433-6133)

PATHFINDER PROGRAM

OAST

PATHFINDER ELEMENT	OAST DIVISION	ELEMENT MANAGER	COORD. CENTER	CENTER MANAGER
PLANETARY ROVER	RC	M. MONTEMERLO (202-453-2744)	JPL	ROGER BEDARD (818-354-4238)
SAMPLE ACQUISITION, ANALYSIS & PRESERVATION	RM	M. HIRSHBEIN (202-453-2859)	JPL	BRIAN MUIRHEAD (818-354-8179)
AUTONOMOUS LANDER	RC	J. DIBATTISTA (202-453-2743)	JSC	KEN BAKER (713-483-2041)
SURFACE POWER	RP	M. LOPEZ-TELLADO (202-453-2856)	LERC	JOHN BOZEK (216-433-6166)
PHOTONICS	RC	M. SOKOLOSKI (202-453-2748)	JPL LARC JSC	JIM CUTTS (818-354-4120) J. CREEDON (804-865-4915) R. JUDAY (713-483-1486)
RESOURCE PROCESSING PLANT	RM	M. HIRSHBEIN (202-453-2859)	JSC	D. MCKAY (713-483-5048)
OPTICAL COMMUNICATIONS	RC	M. SOKOLOSKI (202-453-2748	GSFC JPL	M. FITZMAURICE (286-8942) J. LESH (818-354-2766)
CARGO VEHICLE PROPULSION	RP	E. VAN LANDINGHAM (202-453-2847)	LERC	D. BYERS (216-433-2447)
CHEMICAL TRANSFER PROPULSION	RP	F. STEPHENSON (202-453-2853)	LERC	N. HANNUM (216-433-2457)

PATHFINDER PROGRAM

OAST

PATHFINDER ELEMENT	OAST DIVISION	ELEMENT MANAGER	COORD. CENTER	CENTER MANAGER
HIGH ENERGY AEROBRAKING	RF	S. WANDER (202-453-2820)	LARC	J. WALBERG (804-865-3887)
EXTRAVEHICULAR ACTIVITY EVA/SUITS	RC	J.JENKINS (202-453-2750)	ARC	B.WEBBON (415-694-5984)
SPACE HUMAN FACTORS	RC	J. JENKINS (202-453-2750)	ARC JSC LARC	M. SHAFTO (415-694-6170) B. WOOLFORD(713-483-3701) J. CREEDON (804-865-4915)
HUMAN PERFORMANCE	EB	A. NICOGOSSIAN (202-453-1530)		
PHYSICAL-CHEMICAL LIFE SUPPORT	RP	P. EVANICH (202-453-2858)	ARC	J. LAWLESS (415-694-5900)
BIOREGENERATIVE LIFE SUPPORT	EB	A. NICOGOSSIAN (202-453-1530)		
AUTONOMOUS RENDEZVOUS AND DOCKING	RC	J. DIBATTISTA (202-453-2743)	JSC	D. BROWN (713-483-2041)
IN SPACE ASSEMBLY & CONSTRUCTION	RM	M. HIRSCHBEIN (202-453-2744)	LARC	C. BLANKENSHIP (804-865-2042)

PATHFINDER PROGRAM

OAST

PATHFINDER ELEMENT	OAST DIVISION	ELEMENT MANAGER	COORD. CENTER	CENTER MANAGER
CRYOGENIC FLUID DEPOT	RP	M. LOPEZ-TELLADO (202-453-2856)	LERC	E. SYMONS (216-433-2853)
SPACE NUCLEAR POWER	RP	D. SCHNYER (202-453-2855)	JPL	V. TRUSELLO (818-354-1820)

UNIVERSITY CENTER CONTACTS

OAST

NASA CENTER	UNIVERSITY AFFAIRS OFFICER	TELEPHONE NUMBER
AMES RESEARCH CENTER MOFFETT FIELD, CA	MS. BARBARA HASTINGS	(415) 694-5802
GODDARD SPACE FLIGHT CENTER GREENBELT, MD	DR. GERALD SOFFEN	(301) 286-9690
JET PROPULSION LABORATORY PASADENA, CA 91109	DR. HARRY ASHKENAS	(818) 354-8251
JOHNSON SPACE CENTER HOUSTON, TX	DR. STAN GOLDSTEIN	(713) 483-4724
KENNEDY SPACE CENTER KSC, FL	DR. JIM ALIBERTI	(407) 867-3353
LANGLEY RESEARCH CENTER HAMPTON, VA	DR. SAMUEL MASSENBERG	(804) 865-2188
LEWIS RESEARCH CENTER CLEVELAND, OH	DR. FRANK MONTEGANI	(216) 433-2956
MARSHALL SPACE FLIGHT CENTER HUNTSVILLE, AL	MS. ERNESTINE COTHRAN	(205) 544-0997

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APPENDIX C

Conference Attendee List

Mr	Peter		von Gronefeld		Jet Propulsion	Laboratory
Mr	John		Aaron		NASA Headquarters	
Ms	Barbara	A	Ackerman		TRW	
Mr	Belinda		Adams		NASA Langley	Research Center
	J.R.		Adams	III	McDonnell Douglas	Corporation
Mr	H.E.		Adelson		TRW	
Mr	Carl	S	Ahmed		Technology Transfer	Specialist, Inc
Mr	James	A	Aliberti		NASA Kennedy Space	Center
Ms	Judith	H	Ambrus		NASA Headquarters	
Mr	John	L	Anderson		NASA Headquarters	
Ms	Lynn		Anderson		NASA Lewis Research	Center
Mr	Edward		Andrews		Lockheed Space	Operations
Dr	George	E	Apostolakis		University of	California at L.A.
Ms	Barbara		Askins		NASA Headquarters	
Mr	Norman		Augustine		Martin Marietta	
Mr	Eugene		Austin		NASA Marshall Space	Flight Center
Mr	James		Ball		SDIO	
Mr	William		Ballhaus	Jr	NASA Headquarters	
Mr	William	A	Baracat		General Research	Corporation
Mr	John		Barry		Satellite & Space	
Mr	Eric		Basques		U.S. Congress/Office	of Technology Assess
Mr	Henry	H	Beck		Jet Propulsion	Laboratory
Mr	Gary		Bennett		NASA Headquarters	
Mr	Frank		Berkopec		NASA Headquarters	
Dr	William	P	Bishop		Science Applications	International Corp
	Charles		Blankenship		NASA Langley	Research Center
Ms	Paula	L	Blizzard		Booz, Allen &	Hamilton, Inc.
Mr	Andrew		Bogus		Allied-Signal	Aerospace Company
Mr	Mike		Boland		IBM Corporation	
Mr	William	J	Boone	III	Martin Marietta	Corporation
Mr	Rene		Bossou		SEP/SNECMA Inc	
Mr	Darrell	R	Branscome		NASA Headquarters	
Dr	James		Breckingridge		NASA/JPL	
Mr	Remus		Bretot		NASA Ames Research	Center
Mr	Robert		Bristow		NASA Headquarters	
Mr	James	R	Brown		Pratt & Whitney	
Mr	Joe	H	Brown		Battelle	
Mr	Larry		Brown		Honeywell	
Mr	Frank	S	Brugner		Newport News	Shipbuilding
Mr	John		Bryant		TRW	
Mr	Harm		Buning		University of	Michigan
Ms	Corinne		Buoni		Battelle	
Mr	Jay		Bushman		GTE	
Mr	Jon	R	Busse		NASA Goddard Space	Flight Center
Mr	Anthony	J	Calio		Planning Research	Corporation
Mr	Michael		Callahan		U.S. Congress/Office	of Technology Assess
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The Technology for Future NASA Missions conference was held during the period September 12-13, 1988 at the Capital Hilton in Washington, DC. The conference provided industry and university executives programmatic and technical information on OAST space technology efforts. The conference was jointly sponsored by the American Institute of Aeronautics and Astronautics and the National Aeronautics and Space Administration. First day proceedings were devoted to programmatic discussions of CSTI, Pathfinder, and the Research and Technology Base program. Second day activities included the coverage of technical efforts on a more detailed basis.

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